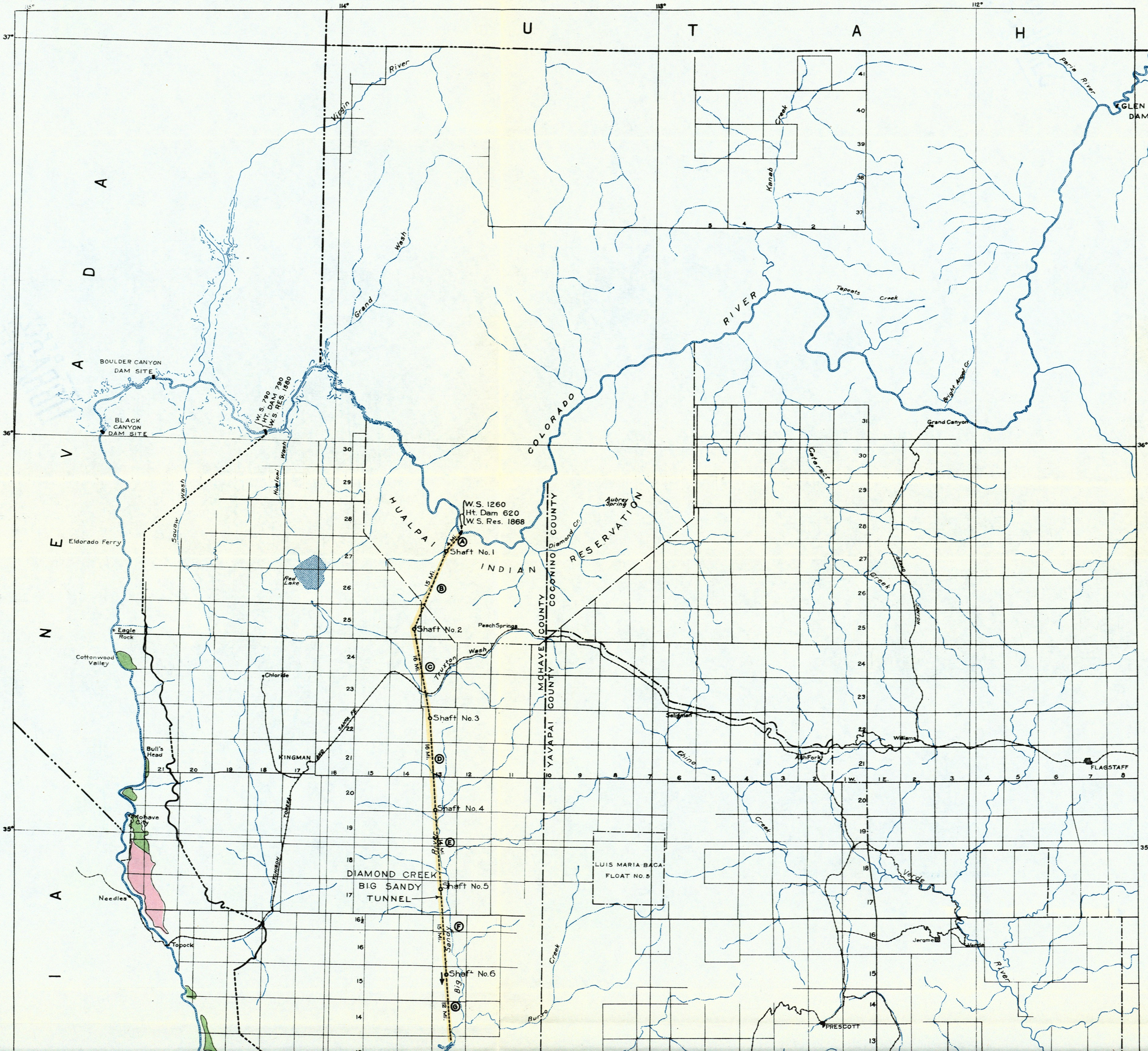
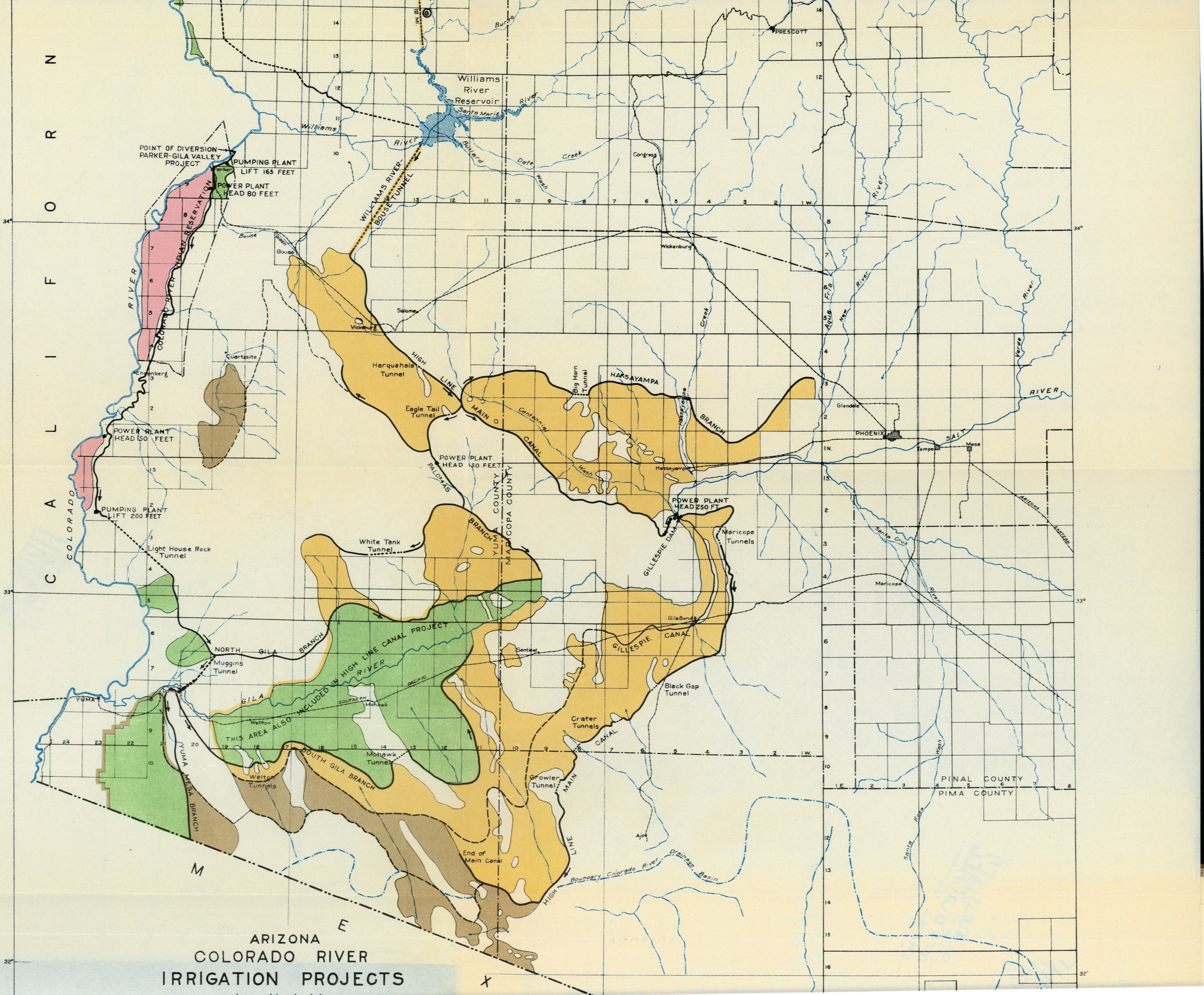
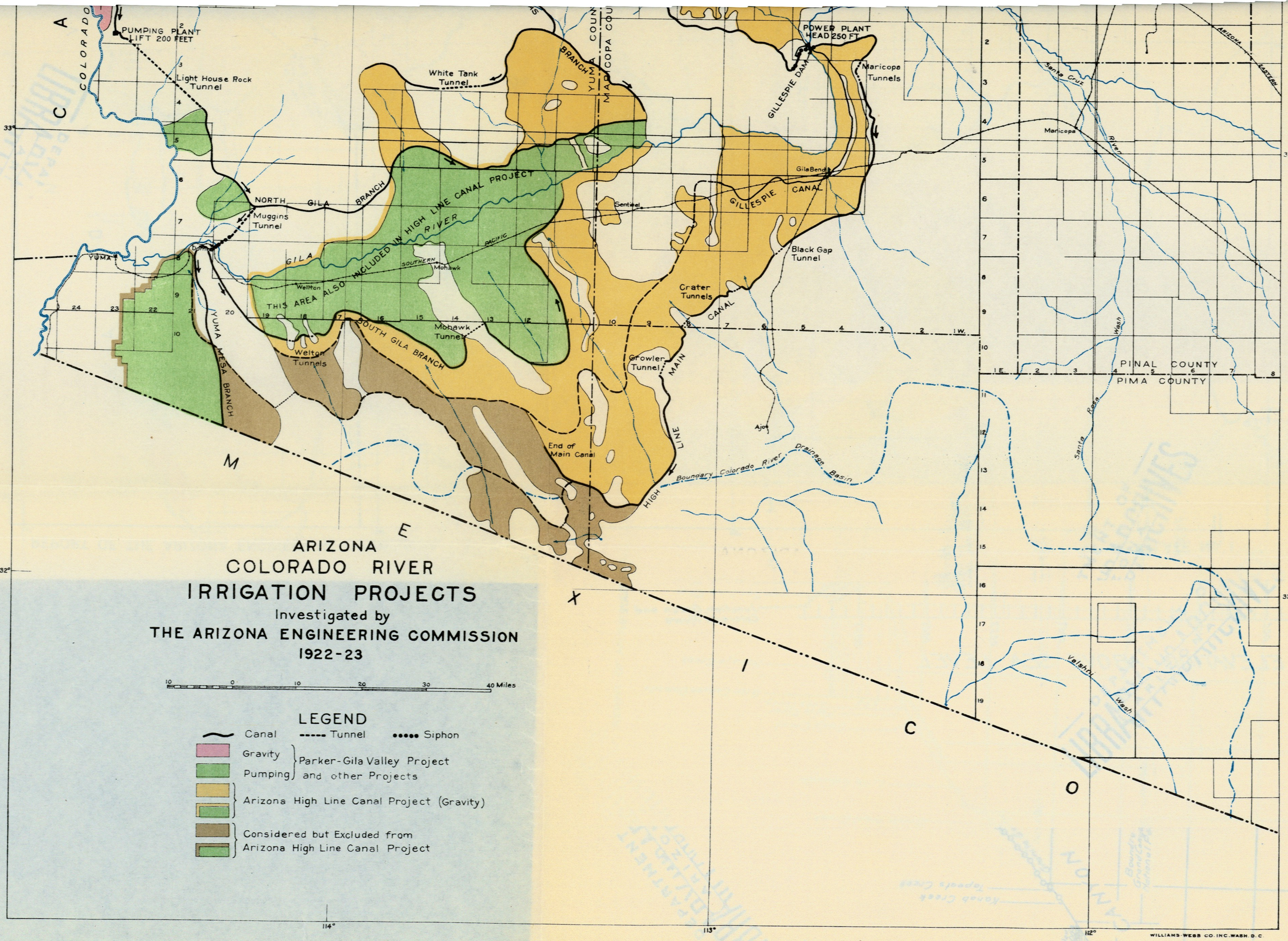

U T A H
N E V A D A
GLEN CANYON DAM SITE
Paria River
Virgin River
Kanab Creek
Grand Wash
Tapeats Creek
Bright Angel Cr.
Grand Canyon
COLORADO RIVER
BOULDER CANYON DAM SITE
BLACK CANYON DAM SITE
W.S. 790
HT. DAM 790
W.S. RES. 1580
Squaw Wash
Hualpai Wash
Red Lake
HUALPAI INDIAN RESERVATION
W.S. 1260
Ht. Dam 620
W.S. Res. 1868
Shaft No. 1
Shaft No. 2
Shaft No. 3
Shaft No. 4
Shaft No. 5
Shaft No. 6
Aubrey Spring
Diamond Cr.
Peach Springs
Truxton Wash
Cataract Creek
MOHAVE COUNTY
COCONINO COUNTY
YAVAPAI COUNTY
Eldorado Ferry
Eagle Rock
Cottonwood Valley
Chloride
KINGMAN
Bull's Head
Mohave City
Needles
Topock
DIAMOND CREEK
BIG SANDY
TUNNEL
Big Sandy
Seligman
Ash Fork
Williams
FLAGSTAFF
Chino Creek
LUIS MARIA BACA FLOAT No. 5
Verde River
Jerome
Verde
PRESCOTT
Burro Creek



ARIZONA
COLORADO RIVER
IRRIGATION PROJECTS
Williams River Reservoir
Williams River
Santa Maria River
Bill Williams River-Bouse Tunnel
POINT OF DIVERSION PARKER-GILA VALLEY PROJECT
PUMPING PLANT LIFT 165 FEET
POWER PLANT HEAD 80 FEET
COLORADO RIVER INDIAN RESERVATION
POWER PLANT HEAD 150 FEET
PUMPING PLANT LIFT 200 FEET
Light House Rock Tunnel
Harquahala Tunnel
Eagle Tail Tunnel
HIGH LINE MAIN CANAL
Centennial Wash
Big Horn Tunnel
HASSAYAMPA BRANCH
POWER PLANT HEAD 150 FEET
PALOMAS BRANCH
White Tank Tunnel
POWER PLANT HEAD 250 FT.
GILLESPIE DAM
Maricopa Tunnels
GILLESPIE CANAL
NORTH GILA BRANCH
Muggins Tunnel
THIS AREA ALSO INCLUDED IN HIGH LINE CANAL PROJECT
GILA RIVER
Welton Tunnels
Mohawk Tunnel
SOUTH GILA BRANCH
YUMA MESA BRANCH
Black Gap Tunnel
Crater Tunnels
Growler Tunnel
End of Main Canal
Boundary Colorado River Drainage Basin
YUMA COUNTY
MARICOPA COUNTY
PINAL COUNTY
PIMA COUNTY
PRESCOTT
Congress
Wickenburg
Salome
Bouse
Vicksburg
Quartzsite
Ehrenberg
Parker
Glendale
PHOENIX
Tempe
Mesa
Hassayampa
Maricopa
Gila Bend
Sentinel
Mohawk
Wellton
Yuma
Ajo
SALT RIVER
Verde River
Agua Fria River
New River
Santa Cruz River
Santa Rosa Wash
C A L I F O R N I A
M E X



ARIZONA
COLORADO RIVER
IRRIGATION PROJECTS
Investigated by
THE ARIZONA ENGINEERING COMMISSION
1922-23
10 0 10 20 30 40 Miles
LEGEND
Canal
Tunnel
Siphon
Gravity
Pumping
Parker-Gila Valley Project and other Projects
Arizona High Line Canal Project (Gravity)
Considered but Excluded from Arizona High Line Canal Project
PUMPING PLANT LIFT 200 FEET
Light House Rock Tunnel
White Tank Tunnel
POWER PLANT HEAD 250 FT.
GILLESPIE DAM
Maricopa Tunnels
NORTH GILA BRANCH
Muggins Tunnel
THIS AREA ALSO INCLUDED IN HIGH LINE CANAL PROJECT
GILA RIVER
SOUTHERN PACIFIC
Mohawk
Wellton
Welton Tunnels
Mohawk Tunnel
SOUTH GILA BRANCH
YUMA MESA BRANCH
YUMA
Sentinel
Gila Bend
GILLESPIE CANAL
Black Gap Tunnel
Crater Tunnels
Growler Tunnel
HIGH LINE MAIN CANAL
End of Main Canal
Ajo
Boundary Colorado River Drainage Basin
Maricopa
Santa Cruz River
ARIZONA EASTERN
Santa Rosa Wash
Vaiva Wash
PINAL COUNTY
PIMA COUNTY
YUMA COUNTY
MARICOPA COUNTY
COLORADO
C A
M E X I C O
33°
32°
114°
113°
112°
WILLIAMS-WEBB CO. INC. WASH. D.C.

REPORT

Based on Reconnaissance Investigation

of

Arizona Land Irrigable From the Colorado River

ARIZONA ENGINEERING COMMISSION
1922 1923

Pasadena, Calif., July 5, 1923.

Hon. Geo. W. P. Hunt,
Governor of Arizona,
(Through State Water Commissioner, Vernon Vaughn),
Phoenix, Arizona.

The Arizona Engineering Commission, which was created for the purpose of determining the amount of land in Arizona that may be feasibly irrigated with the waters of the Colorado River, submits herewith its report.

E. C. LaRue has inserted conclusions and recommendations regarding the adequacy of the water supply and the need for action to safeguard, if possible, Arizona's interests in the waters of the Colorado River. In all other matters the Commission is in full agreement.

Respectfully submitted,

E. C. LaRUE, (Chairman)
Hydraulic Engineer,
U. S. Geological Survey,
Pasadena, Calif.

PORTER J. PRESTON,
Project Manager,
U. S. Reclamation Service,
Yuma, Arizona.

H. E. TURNER,
Irrigation Engineer with
Arizona State Water Commissioner,
Phoenix, Arizona.

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FOREWORD

In this report will be found a brief description of each project investigated, a suggested plan of development, the location and extent of areas that may be irrigated, with conclusions and recommendations regarding the feasibility of the projects and the need for further investigations. These data are supported by more detailed information given in the Appendices. The reader who wishes to study the report in detail should look up all references. The pictures* will be found in a separate album, designated Appendix B.

(*) (Pictures referred to in this report, both in the text and on certain of the maps, have been omitted from this publication as a matter of economy.)

INTRODUCTION

Purpose of Report

The purpose of this report is to show how much land in the State of Arizona can be irrigated with the waters of the Colorado River.

The Arizona Engineering Commission wishes the reader to keep in mind that this is a reconnaissance report. The sum of $18,000 was made available to the Commission, while a report to determine definitely the feasibility of the projects under consideration would require a topographical survey covering a large region, which survey alone would cost from $250,000 to $300,000. The Commission made such surveys as were deemed necessary to determine whether or not the respective projects have sufficient merit to justify a further expenditure of money on detailed surveys and reports.

Authority

The Arizona Engineering Commission was created by State Water Commissioner, W. S. Norviel. For authority of State Water Commissioner, see Session Laws of Arizona, 1922, (Special Session), Chapter 42, Section 43.

Personnel of Commission

The personnel of the Commission, which was organized August 15. 1922, is as follows:

E. C. LaRUE (Chairman),
Hydraulic Engineer,
U. S. Geological Survey,
Pasadena, Calif.

PORTER J. PRESTON,
Project Manager,
U. S. Reclamation Service,
Yuma, Arizona.

H. E. TURNER,
Irrigation Engineer with
Arizona State Water Commissioner,
Phoenix, Arizona.

Acknowledgments

The plan to irrigate several million acres of land in Arizona by diverting the Colorado River at or near Boulder Canyon was first presented by R. M. Stene, in September, 1920. (See Arizona Republican, issue of September 26, 1920). At a later date a study was made of this project by Robert H. Williams of Phoenix. George H. Maxwell, Executive Director of the National Reclamation Association has taken the lead in the work of informing the people of Arizona regarding the possibility for development on the Lower Colorado. P. R. Helm of Phoenix, speaking in behalf of a number of business men, has informed the Commission as to the character of the investigation desired.

Various plans have been suggested for bringing the waters of the Colorado to lands in Arizona. Every suggestion presented has been investigated by the Arizona Engineering Commission. The Commission wishes to express its appreciation of the assistance rendered by the above named gentlemen.

The Commission is indebted to Prof. G. E. P. Smith of the University of Arizona, who offered suggestions regarding a plan to reclaim low lands lying on the north and south side of the Gila River by means of a dam and pumping plant to be located on the Colorado River at Cocopah point.

The Commission is indebted to E. Ross Householder and L. H. Foster of Kingman, who assisted the Commission in planning its work in Mohave County. The officers of the Gila Water Company assisted the Commission by furnishing maps of its projects and definite information regarding the foundation and physical conditions at the Gillespie dam.

In the desert region southwest of Ajo there are no settlements whatever and but few places where water can be obtained. The Commission wishes to express its appreciation for the assistance rendered by Mr. T. Hicklin, superintendent of the Tucson, Cornelia & Gila Bend Railroad, in planning the desert work near the Mexican boundary.

Field Work

Actual field work was begun by the Commission in September, 1922, and completed in May, 1923. The first work undertaken was that of running a line from Castle Dome plain east and on the north side of Gila River to determine how much land could be irrigated under the 600 foot contour.

All possible dam sites and irrigable land adjacent to the river on the Arizona side, between the mouth of the Virgin River and Yuma, were investigated during the period October 20-November 18, 1922. Two motor boats were used, the Commission being assisted by three additional men. Surveys were made when deemed necessary.

The second part of the investigation consisted of the work of determining an approximate location for a high line canal and the location and extent of lands which might be irrigated. A further study, in the field, was made of the plan to divert the water at a dam on the Colorado River above Parker, the gravity canal to lead to Lighthouse Rock where the water would be pumped 200 feet to reclaim lands north and south of Gila River.

In carrying on this work, the Commission was assisted by four to eight additional men. These investigations were completed during the first week in May, 1923. Briefly stated, the investigation consisted of making sufficient surveys to determine with fair accuracy, the position of possible high or low line canals. About 200 miles of line were run in the vicinity of the Williams River, where topography was taken at two possible dam sites in the canyon of the Williams River, and the flowage line of the Williams River reservoir site was surveyed.

Below the Williams River, surveys were made to determine the area of land which could be irrigated in Bouse and Quartzsite valleys, the Centennial Valley and large areas north and south of the Gila River, below the Gillespie dam. In all more than 1,000 miles of line were surveyed.

Office Work

The office work, which was completed in about two months, required the services of from four to seven engineers. The greater part of this time was spent in plotting the surveys, measuring the areas of irrigable land, designing structures, computing yardage of earth and rock throughout the entire system and estimating the cost of the projects.

Sonderegger and Hincks, consulting engineers, Los Angeles, assisted by N. Bostwick, designing engineer, prepared the designs for all structures, including dams, siphons, wasteways, tunnel and canal sections. This firm also assisted with the work of estimating the cost of the irrigation system.

PROJECTS INVESTIGATED

General Statement

It should be kept in mind that the investigations made by the Arizona Engineering Commission covered only the Arizona side of the Colorado River. This being a reconnaissance investigation, the Commission made only such surveys as were deemed necessary to show with fair accuracy the possibilities for development. The description of a number of projects will be given, together with recommendations as to whether or not these projects have sufficient merit to justify the further expenditure of money on detailed surveys.

Cottonwood Valley

Between Black Canyon and Pyramid Canyon, there is an open basin about 30 miles long, the central part of which is known as Cottonwood Valley. This valley is located approximately 50 miles north of Needles and 30 miles north of Mohave. Eldorado Ferry, Davis Mountains, Round Island and Eagle Rock are located in the basin of Cottonwood Valley. See pictures 26, 27, 28, 29, 30, 31, 32 and 33.

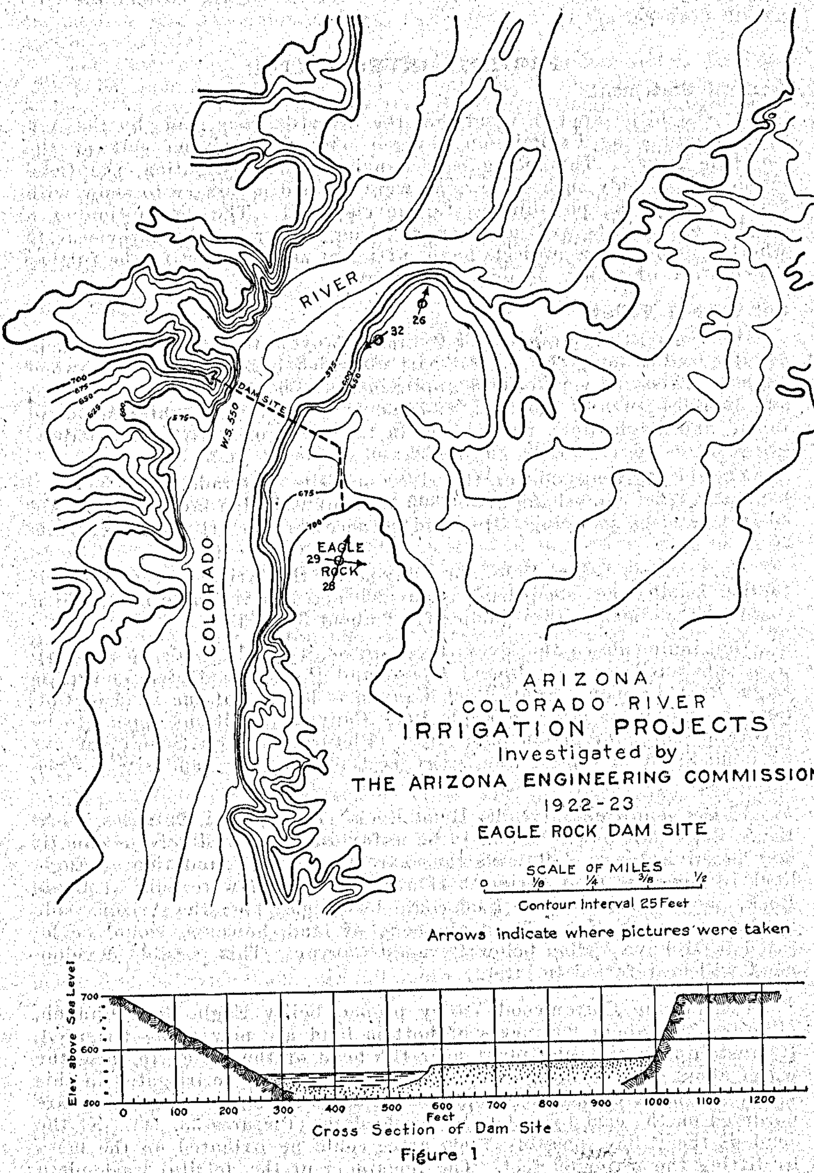
On the Arizona side of the river opposite Eldorado Canyon, there is a small tract comprising about 300 acres of irrigable land, which could be reclaimed by pumping. It would be necessary to lift the water from 20 to 30 feet.

Three miles below Eldorado Canyon on the Arizona side, there is another small tract, comprising about 200 acres of irrigable land, which could be reclaimed with a pump lift of about 30 feet.

Continuing down the river there are no irrigable lands on the Arizona side until we pass Round Island and the short stretch known as Eagle Rock Canyon. Eagle Rock Canyon is located at the head of Cottonwood Valley proper. In Eagle Rock Canyon, conditions appear to be favorable for a diversion dam site. (Picture 32). Sufficient surveys were made to determine the cross section at the dam site. (See Figure 1).

If the conditions at Bulls Head Rock, (Picture 42), 22 miles below Eagle Rock Canyon are found to be unfavorable for a diversion dam, it may be advisable to determine the character of the foundation at Eagle Rock by diamond drill borings. If a diversion dam were built at Eagle Rock, about 5,000 acres of land could be irrigated on the Arizona side in Cottonwood Valley. The main body of land, however, would be located in Mohave Valley below Pyramid Canyon. This possible development will be referred to later.

Considering Cottonwood Valley proper, below Eagle Rock Canyon, (Picture 33), about 200 acres of bottom land are now being irrigated. By installing a pumping plant near the head of the valley to raise the water about 40 feet, approximately 3,000 acres could be irrigated in this valley on the Arizona side. The bottom lands in Cottonwood Valley are bordered on the east by a detrital wash plain, (Pictures 33, 34). At the head of the valley, possibly 1,000 acres could be irrigated on the mesa by lifting the water 80 feet. The remainder of the detrital wash plain bordering Cottonwood Valley is cut by many washes and is deemed unsuitable for agricultural purposes.



RIVER
COLORADO
DAM SITE
W.S. 550
EAGLE ROCK
ARIZONA
COLORADO RIVER
IRRIGATION PROJECTS
Investigated by
THE ARIZONA ENGINEERING COMMISSION
1922-23
EAGLE ROCK DAM SITE
SCALE OF MILES
0 1/8 1/4 3/8 1/2
Contour Interval 25 Feet
Arrows indicate where pictures were taken
Elev. above Sea Level
Feet
Cross Section of Dam Site

Figure 1

SUMMARY OF IRRIGABLE LANDS IN COTTONWOOD VALLEY, ARIZ.

Unit	Irrigable by Gravity System	Irrigable by Pumping Lift	Area
	acres	ft.	Acres
Opposite Eldorado Canyon	0	20-30	300
3 miles below Eldorado Canyon	0	30	200
Cottonwood Valley below)	0	40	3000
Eagle Rock)		80	1000
TOTALS	0	-	4500

MOHAVE VALLEY

The Mohave Valley is a large basin extending from Bulls Head Rock in the Pyramid Canyon to the Needles Peaks, a distance of about 35 miles. The center of the basin is occupied by a broad flood plain, having an area of more than 50,000 acres. This is bordered on both sides by terraced gravel bluffs, from which long graded alluvial slopes extend to the bordering mountains, joining the slopes at altitudes of 2500 to 3000 feet, (See Figure 2).

Bulls Head Unit

Beginning about one mile below Bulls Head Rock there is a narrow strip of land on the Arizona side of the river, about three and one-half miles long. About 500 acres could be irrigated with a pump life of approximately 25 feet. For convenience we have called this Bulls Head unit.

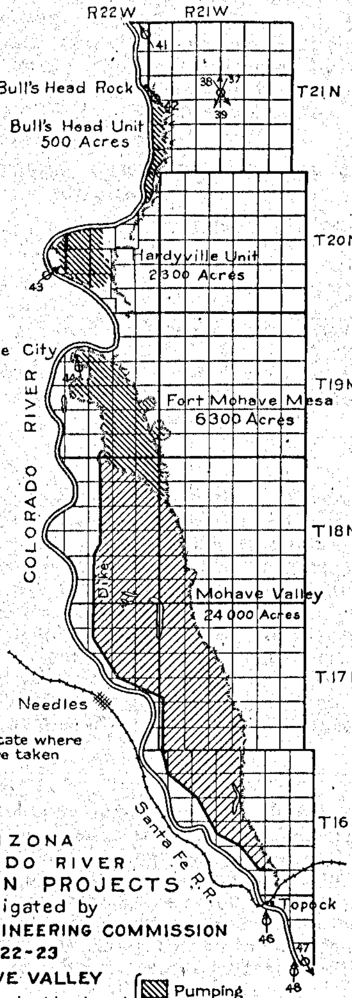
Hardyville Unit

Immediately north of Fort Mohave at Hardyville, (Picture 43) there is a tract of land comprising 2,300 acres, which could be irrigated by a pump lift ranging from 20 feet to 80 feet, (See Figure 2).

Fort Mohave Mesa

The Fort Mohave Mesa begins at the Fort Mohave Indian School and extends in a southeasterly direction for a distance of about 6 miles, (Picture 44). The mesa comprises an area of about 6,300 acres, which are classed as irrigable. Approximately one-half of this area could be reclaimed by lifting the water 60 feet. To reclaim the remainder of the tract would require a maximum pump lift of about 150 feet. The location of the Fort Mohave Mesa is shown on Figure 2.

The main Mohave Valley comprising the bottom lands, extends from Fort Mohave on the north to Topock on the south, a distance of about 25 miles, with a maximum width of about 5 miles. Several attempts have been made to reclaim these bottom lands. Perhaps the most extensive irrigation works were constructed in 1910 by the Cotton Land Company. It is said that more than $350,000 was spent by this Company in building levees and constructing canals. These levees were later destroyed. Some money was spent by the United States Indian Service to reclaim a small area of bottom land near the Fort Mohave Indian School. The irrigation works have been abandoned and at the present time (1923) practically no lands are being irrigated in the Mohave Valley. For a detailed description of the Fort Mohave Indian



ARIZONA
COLORADO RIVER
IRRIGATION PROJECTS
Investigated by
THE ARIZONA ENGINEERING COMMISSION
1922-23
MOHAVE VALLEY
Showing Irrigable Land

Figure 2

Reservation, see Appendix A, Hearings Before the Committee on Irrigation of Arid Lands, House of Representatives, Sixty-Seventh Congress, Scond Session on H. R. 11449 by Mr. Swing.

Figure 2 shows the bottom lands of Mohave Valley, which may be irrigated by gravity, provided substantial diversion works can be constructed in the Colorado River near Fort Mohave. During unusual high water, these lands are subject to overflow. It would, therefore, be necessary to construct a system of levees to protect the irrigation works. When the floods of the Colorado River are prevented by the construction of flood control works above, it will no doubt be feasible to reclaim the bottom lands in Mohave Valley. The area of bottom lands, which may thus be reclaimed, is about 24,000 acres.

SUMMARY OF IRRIGABLE LANDS IN MOHAVE VALLEY, ARIZONA

Unit	Irrigable by Gravity System	Irrigable by Pumping Lift	Irrigable by Pumping Area
	acres	feet	acres
Bulls Head Unit	0	25	500
Hardyville Unit		20- 80	2,300
Fort Mohave Mesa	0	60-150	6,300
Mohave Valley bottoms	24,000		0
TOTALS	24,000		9,100

The land in the above table, together with 5,000 acres in Cottonwood Valley, making 38,000 acres in all, could be irrigated by gravity if a diversion dam to raise the water 100 feet were constructed in Eagle Rock Canyon. The main canal from Eagle Rock to Fort Mohave mesa would be about 40 miles long. On account of the rough topography on the Arizona side bordering Pyramid Canyon, possibly 15 miles of the main canal would be in tunnel. The balance of the main canal would pass through a detrital plain cut by washes. Such a canal would be rather expensive. It is not likely that this plan of development to reclaim 38,000 acres would be feasible unless a considerable amount of power could be developed at the diversion dam. The project is mentioned here only as a possibility.

Blankenship Valley

At the lower end of Mohave Canyon, (Picture 49, 50) 8 miles below Topock, (Picture 46) there is a small basin on the Arizona side of the river known as Blankenship Valley. The head of the valley is marked by a large rock on the left bank of the river, 80 or 90 feet in height, (Picture 52). Due to the many washes, the lands in Blankenship Valley are not first class. However, at some future time it may be feasible to reclaim possibly 800 acres in this valley by the installation of a pumping plant at Mohave Rock to raise the water 50 feet, see Figure 3.

Chemehuevis Valley

Immediately below Blankenship Valley there is a comparatively large basin on both sides of the river known as the Chemehuevis Valley. Lying on both sides of the river near the lower end of this valley are several thousand acres of land, which may be reclaimed by irrigation. (Pictures 55, 56, 58, 59, 60). Near the head of Chemehuevis Valley the elevation of the water surface of the Colorado River at low water is

412 feet above sea-level. This point is 5 miles by river below Mohave Rock. A pumping plant located near this point to raise the water to elevation 450 to 475 feet above sea-level, would make possible the irrigation of 4,400 acres of land on the Arizona side of the river. Of this area about 3,000 acres are bottom lands and 1,400 acres mesa land, all first class. (See Figure 3).

Below Chemehuevis Valley for a distance of 25 miles, the Colorado River passes through the Whipple Mountains. The mountains extend to the river on both sides until the Parker Valley is reached.

Parker Valley

All of Parker Valley is embraced within the boundary of the Colorado River Indian Reservation. A definite plan for the irrigation of a net area of 104,000 acres of bottom lands on the Parker Indian Reservation has been worked out by the Department of Interior, U. S. Indian Irrigation Service. A complete report on this project is published in Appendix A, Hearings Before the Committee on Irrigation of Arid Lands, House of Representatives, Sixty-Seventh Congress, Second Session, Hearings on H. R. 11449 by Mr. Swing. As of date 1920, the Chief Engineer of the U. S. Indian Irrigation Service has estimated that a complete gravity irrigation system to supply water to a net area of 104,000 acres, including a permanent concrete diversion dam across the Colorado River could be built for $7,234,600.00 or at a cost per acre of $69.50. In addition to this area, which may be reclaimed by a gravity system, a tract comprising about 6,000 acres on the Parker mesa may be irrigated by pumping. It would be necessary to lift the water about 150 feet. (See Plates I and II, in Pocket).

Cibola Valley

Cibola Valley is situated on the Arizona side of the river in Yuma County. It is about 20 miles south of the lower end of the Parker Valley and is across the river from the lower part of Palo Verde Valley.

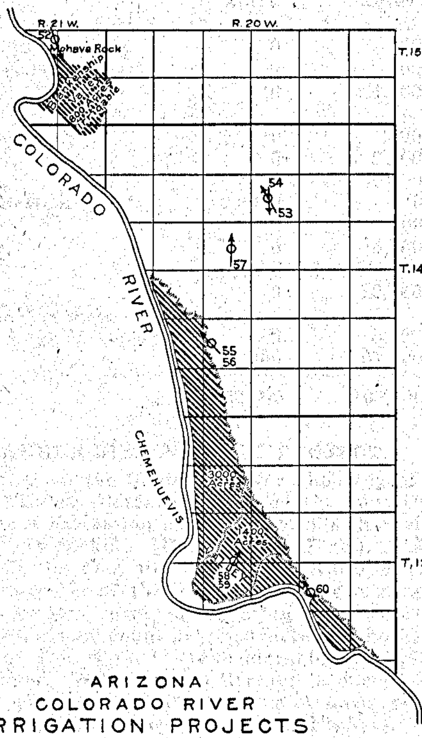
In 1913, the land owners in Cibola Valley formed an irrigation district. A complete irrigation and levee system was laid out and bonds were voted for its construction. At the present time (1923) practically no lands have been reclaimed in the valley.

When the floods of the Colorado River have been placed under control by the construction of storage works above, it will then be practicable to irrigate about 16,000 acres in Cibola Valley. In the past this valley has been subject to overflow, but with the river under control, no doubt the valley could be protected at reasonable expense by the construction of a permanent levee system. (See Plates I and II in Pocket).

Miscellaneous Projects

A careful examination was made of the Arizona side of the river between the mouth of the Virgin River and Eldorado Ferry. Throughout this distance, mountains or bluffs rise from the river's edge. In this section there are no irrigable lands on the Arizona side. (Pictures 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14, 15, 16, 17, 18). Between Eldorado Ferry and the lower end of Cibola Valley, all irrigable lands including isolated tracts of 200 acres or more have been referred to in the preceding pages.

Between Cibola Valley and Laguna dam there are a number of small tracts of bottom land on the Arizona side, which may be reclaimed by low pump lifts, probably less than 20 feet. An estimate of the area of these tracts of bottom land is based on a map prepared by the U. S. Reclamation Service in June, 1912. The aggregate area of bottom land on the Arizona side of the river, classed as irrigable between Cibola Valley and Laguna dam is 3,400 acres.



ARIZONA
COLORADO RIVER
IRRIGATION PROJECTS
Investigated by
THE ARIZONA ENGINEERING COMMISSION
1922-23
CHEMEHUEVIS VALLEY
Showing Irrigable Land ▧ Pumping
Arrows indicate where pictures were taken

Figure 3

SUMMARY OF NET IRRIGABLE AREAS IN ARIZONA BELOW BOULDER CANYON

(Low lands adjacent to the river)

Unit	Irrigable Areas Gravity Acres	Pumping Acres	Total Acres
Opposite Eldorado Canyon	0	300	300
3 miles below Eldorado Canyon	0	200	200
Cottonwood Valley	0	4,000	4,000
Mohave Valley			
Bulls Head Unit	0	500	500
Hardyville Unit	0	2,300	2,300
Ft. Mohave mesa	0	6,300	6,300
Mohave Valley Bottoms	24,000	0	24,000
Blankenship Valley	0	800	800
Chemehuevis Valley	0	4,400	4,400
Parker Valley	104,000	6,000	110,000
Cibola Valley	0	16,000	16,000
Miscellaneous tracts between Cibola Valley and Laguna Dam	0	3,400	3,400
Yuma project	54,000	61,000	115,000
TOTALS	182,000	105,200	287,200

PARKER-GILA VALLEY PROJECT

There is a section on the Colorado River about ¾ of a mile above the Colorado River Indian Reservation where the conditions appear to be favorable for the construction of a combination diversion and power dam. See Plate III, in pocket. (Pictures 66, 67, 68). The elevation of the water surface at the dam site during low water is 358 feet above sea level. For the purposes of this report, we have assumed that a dam can be built to raise the water to elevation 457. Starting from the dam at elevation 440, canals could be constructed on both the California and Arizona side of the river. A considerable acreage could be reclaimed in this manner. With a pump lift not to exceed 200 feet, more than 700,000 acres could be irrigated on the Arizona side and 310,000 acres on the California side. (See Plate II in Pocket).

The plan of development would be as follows:

Arizona Lands

On the Arizona side the main canal leading from diversion dam to a point about two miles south of Parker, would carry sufficient water to irrigate about 752,000 acres, water for about 12,000 acres on the mesa east of Parker having been supplied. At a point on the mesa about two miles south of Parker, sufficient water to irrigate a net area of about 104,000 acres of bottom land would be dropped utilizing a head of 80 feet for power purposes. From this power plant south to Cibola Valley, the main canal would carry sufficient water to irrigate 648,000 acres. At Cibola Valley, water for the irrigation of 16,000 acres of bottom land could be dropped, utilizing a head of about 150 feet for power purposes. From Cibola Valley to a point 6 miles northeast of Lighthouse Rock, the main canal would have a capacity sufficient to serve 632,000 acres. At Lighthouse Rock, (Pictures 76, 77, 78, 79, 80) the water would be lifted 200 feet, or to elevation 600 feet above sea-level. The pumped water would be carried through Lighthouse Rock tunnel, about 16 miles long, to a point in the valley 5 miles north of Castle Dome Landing. See Profile Figure 4.

Three plans for irrigating lands on the north and south side of the Gila River were considered. Under the first plan studied, the water would be carried on the north side of Gila River to Sentinel dam site, where by means of a siphon, the water would be carried to the south side to a canal leading as far west as the Gila Mountains. Under this plan about 468,000 acres could be irrigated. See plates I and II.

Under another plan, the water for lands on the south side of the Gila River would be carried to a point near Mohawk by means of a 12 mile spihon. From Mohawk the water would be carried both east and west to reach the lands on the south side of the river.

The third plan, and the one which may be the best, provides for the construction of a siphon, crossing the Gila River at Dome. The lands on the north side of the river would be irrigated from a canal which would end near Sentinel dam site. At Dome sufficient water would be carried across the Gila to reclaim 430,000 acres on the south side of the river. This plan includes the irrigation of 100,000 acres on the Yuma mesa and 330,000 acres on the south side of the Gila between Dome and Sentinel dam site.

Only meager data are available. It was, therefore, not possible to go into much detail in attempting to estimate the cost of irrigating lands in the Gila Valley under the three plans of development. The third plan mentioned, which provides for a siphon at Dome, appears to be the best. This plan of development will be considered in estimating the cost of the Parker-Gila Valley project.

The following table shows the amount of land on the Arizona side of the river that may be irrigated under the Parker-Gila Valley project.

NET IRRIGABLE AREAS UNDER PARKER-GILA VALLEY PROJECT ARIZONA SIDE

Unit	Irrigable Areas Gravity Acres	Pumping Acres	Total Acres
Parker Mesa	4,000	8,000	12,000
Colorado River Indian Res. (bottom)	104,000	0	104,000
Cibola Valley	16,000	0	16,000
Lands north of Gila River	0	202,000	202,000
Lands south of Gila River	0	430,000	430,000
TOTALS	124,000	640,000	764,000

California Lands

The Commission did not investigate in the field, the possibilities for development by irrigation on the California side. However a study of available reports indicates that a canal on the California side would reach the Palo Verde mesa at elevation 420 feet above sea level. It is, therefore, apparent that a part of the Palo Verde mesa could be irrigated by gravity and the remainder of these lands and all lands included in the Chucawalla Valley project could be irrigated with a maximum pump lift not exceeding 130 feet. It is known that some lands between the proposed Parker diversion dam and the Blythe intake could be irrigated. We have estimated that a total of 50,000 acres could be irrigated from the main canal on the California side above the Blythe intake. The data given in the following table show in a general way the possibilities for irrigation development on the California side, providing a diversion dam should be built at the Parker dam site.

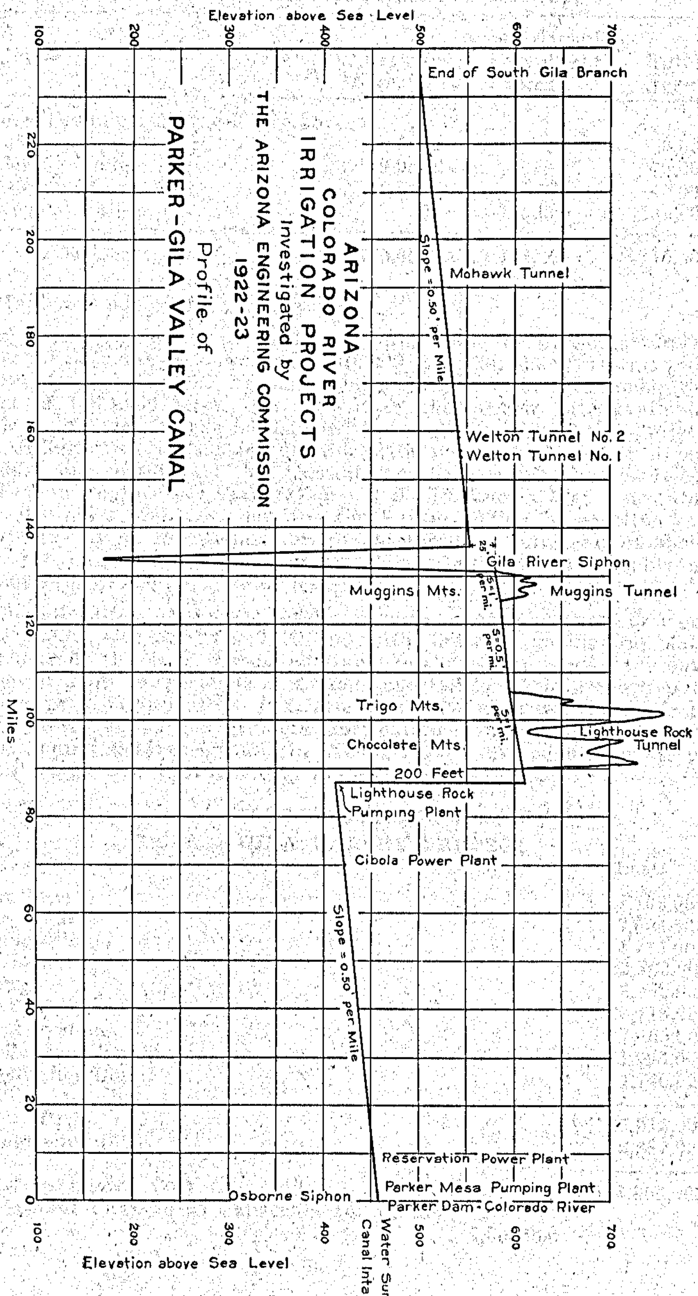

ARIZONA
COLORADO RIVER
IRRIGATION PROJECTS
Investigated by
THE ARIZONA ENGINEERING COMMISSION
1922-23
Profile of
PARKER-GILA VALLEY CANAL
Elevation above Sea Level
Miles
End of South Gila Branch
Slope = 0.50' per Mile
Mohawk Tunnel
Welton Tunnel No. 2
Welton Tunnel No. 1
Gila River Siphon
Muggins Mts.
Muggins Tunnel
S=1 per mi.
S=0.5' per mi.
Trigo Mts.
Chocolate Mts.
Lighthouse Rock Tunnel
200 Feet
Lighthouse Rock Pumping Plant
Cibola Power Plant
Slope = 0.50' per Mile
Reservation Power Plant
Parker Mesa Pumping Plant
Parker Dam - Colorado River
Osborne Siphon
Water Surface at Canal Intake = 457' El.

Figure 4

PARKER-GILA VALLEY PROJECT
LANDS IRRIGABLE ON CALIFORNIA SIDE

Unit	Area Irrigable Gravity Acres	Pumping(1) Acres	Total Acres
Between Diversion dam and Blythe Intake	50,000	0	50,000
Palo Verde Valley	79,000	0	79,000
Palo Verde Mesa	20,000	25,000	45,000
Chucawalla Valley	0	136,000	136,000
TOTALS	149,000	161,000	310,000

(1) Maximum pump lift, 130 feet.

It, therefore, seems that a canal leading from the Parker diversion dam could be made to serve about 310,000 acres on the California side and 764,000 acres on the Arizona side, making a total area under the project of 1,074,000 acres. On account of the meager data available, only a rough estimate can be made of the probable cost of this project. Some definite information is available with respect to the main diversion dam, due to the fact that this site has been studied by the Beckman-Linden Engineering Corporation. It is also known that a net area of 104,000 acres of bottom land on the Parker Indian Reservation can be irrigated by an independent gravity system at a total cost of about $75.00 per acre. The bottom lands in Cibola Valley could probably be reclaimed for $75.00 per acre or less.

The allocation of the cost of the diversion dam and three or more power plants, will be difficult, even with definite engineering data available. At this time it seem equitable to charge the cost of the dam and power plant to the lands in Arizona and California in proportion to the acreage to be irrigated. It is also assumed that it would be fair to levy a charge of $100.00 per acre for bottom lands irrigated on the Parker Indian Reservation and in Cibola Valley. A rough estimate of the cost of the Parker-Gila Valley project is given below.

COST SUMMARY
PARKER-GILA VALLEY PROJECT

		Cost.
Parker Dam		$ 4,700,000
Power Plants		3,604,000
Pumping Plants		4,715,000
Tunnels		33,302,000
Siphons		18,682,000
Main Canals		25,715,000
Lateral System		11,460,000
Miscellaneous Structures		1,995,000
Transmission Line		1,740,000
Total		$105,913,000
Contingencies 15%		15,887,000
Total Construction Cost		$121,800,000
Less Amount Charged to California for Parker Dam	$ 2,000,000	

Less Charge of $100.00 per acre for 124,000 acres in Parker and Cibola valleys	12,400,000	
	$14,400,000	14,400,000
Net cost chargable to 640,000 acres		$107,400,000

Est. cost per acre $168.00.

Annual Cost of Operation, Power and Pumping Plants

Salaries	$ 46,000
Maintenance and depreciation	235,000
Purchase of Power	3,440,000
Total	$3,721,000

Annual Operating cost for pumping per acre served, $5.82.

ARIZONA HIGH LINE CANAL PROJECT

General Plan

In Yuma and Maricopa Counties in Southwestern Arizona there are some 2,000,000 acres of desert land, which is suitable for agricultural development if water for its irrigation can be made available. It has been proposed to reclaim these lands by diverting the Colorado River at some point between Boulder Canyon and Diamond Creek. The greater part of the land included in the project is first class for agricultural purposes. If these lands are to be reclaimed by irrigation, the water supply must be obtained from the Colorado River. There is no other source of supply. If a feasible plan cannot be worked out, these lands must remain as a barren desert waste forever. The Arizona Engineering Commission fully appreciates its responsibility in reporting on this project and it believes that it has given due consideration to every plan suggested for the reclamation of 2,000,000 acres of land in Arizona by using the waters of the Colorado River.

ALTERNATE PLANS

Plan A, (Blake's Report)

Under the direction of the State Water Commissioner, Mr. H. E. Blake, Civil Engineer, made a preliminary field investigation and prepared a final report in the Fall of 1921. The plan investigated by Mr. Blake called for the construction of a dam at Boulder Canyon to raise the water 530 feet, or to elevation 1233 feet above sea-level. The high line canal would divert from the Boulder Canyon dam at elevation 1,085 feet above sea-level. The canal from Boulder Canyon would be located on the west slope of the Black Mountains to a point near the head of Cottonwood Valley, thence following south over detrital wash plains to the Santa Fe railroad near Franconia. From the Santa Fe Railroad the canal would be carried around the Needles Peaks, thence south to the Williams River. It was proposed to cross the Williams River by means of a siphon at a point about 6 miles above its mouth, thence by means of a tunnel or canal, the water would be carried to Bouse Valley, reaching this valley at elevation about 930 feet above sea-level. The canal would follow south into Quartzsite Valley turning west following the west side of Dome Rock and Trigo mountains to Lighthouse Rock, thence in an easterly direction to Castle Dome Valley in the Gila drainage basin. Such a canal would reach Castle Dome Valley at elevation about 685 feet above sea-level. According to Mr. Blake, "The entire irrigable acrage under the proposed canal throughout its entire length would be approximately 496,000 acres." Mr. Blake also considered a plan to reclaim large areas in the Gila Basin by means of a pump lift of 650 feet. Mr. Blake closed his report with the following summary:

"Diverting and carrying water across a hot, arid country without crossing any large bodies of irrigable land until a point 470 miles south of its diversion is reached, would be a very precarious undertaking. In fact, it could not be considered feasible unless these lands under irrigation were of such value that cost could not be considered.

"This is not the case and many acres of land in Arizona can be reclaimed at a cost much less per acre than would be the case under this project.

"The construction costs of the proposed canal are estimated at a lower figure than it would be possible to build at the present time, but these estimates are given to show that at the lowest possible cost during normal times with an open canal, the expense would be enormous.

"If a detailed survey of the canal line through its entire length were undertaken with a report on the different classes of construction and cost, the entire appropriation for this work would be insufficient. For this reason only a hurried reconnaissance was made to the effect that if the project appeared feasible a more detailed survey would be made.

"However, it is believed that this report is sufficient to show that the project is not feasible at the present time.

"It also appears from a study of the Colorado River that the reclamation of all the lands subject to economical irrigation in the drainage basin of the river above the proposed Boulder Canyon Dam, will not effect the future development of all lands in Arizona and California under storage capable of using this water, and it does not appear necessary to enact legislation to protect the future rights to the use of this water, or to enter into agreements with the other interested states as to their future use of this water for irrigation."

Mr. Blake spent but a comparatively short time in the field. No instrumental surveys were made, it being necessary for him to determine elevations by means of an aneroid barometer.

Considering the time spent on the work, Mr. Blake should be commended for the valuable report prepared by him. This report showed the impracticability of the plan to build a diversion dam at Boulder Canyon to raise the water to the 1235 foot level for the reclamation of lands in Southwestern Arizona.

Plan B

Before entering the field, the Arizona Engineering Commission was aware of the fact that to be feasible, a high line canal project must involve a plan to carry the water to Bouse Valley at an elevtion of 1200 feet or more above sea-level. The Commission, therefore, first considered a plan to build a diversion dam at Boulder Canyon to raise the water to elevation 1350 feet above sea-level, the construction of a tunnel from Squaw Wash through the Black Mountains, to a point opposite Eldorado Ferry, following south on practically the same location as far as the Williams River, as that given in the Blake report. At the Williams River, the Commission proposed to build a high dam in the Box Canyon, the high line canal to be carried across on top of the dam. In order to reach the Williams River at elevation 1300 feet, it would be necessary to construct a canal on the very flat grade of 25/100 cf a foot to the mile.

There being no reservoir sites near the lands to be irrigated by means of which the flow can be regulated, it would be necessary for the canal from Boulder Canyon to have a capacity of 17,500 second-feet to serve 2,000,000 acres. Such a canal constructed on the grade of 25/100 of a foot to the mile would cost on an average, about $1,000,000 per mile for canal in rock, $550,000 per mile in earth and $7,000,000 per mile for a four barreled tunnel. The length of the canal from Squaw Wash to the Williams River dam site would be about 150 miles, with 50 miles of canal in earth, 20 miles in rock and 80 miles in tunnel. The cost of such a canal would, therefore, be approximately $607,000,000. It is apparent that a canal constructed on this grade would be infeasible. Some of the rough country through which such a canal would pass is shown in Appendix B, see pictures Nos. 18 to 39, 53, 54, 61 and 62.

Plan C

Assuming foundation conditions favorable, an excellent dam site was found in the Box Canyon of the Williams River. The elevation of the water surface at the dam site is 960 feet above sea level. It was found that a dam could be built at this point to raise the water 460 feet or to the 1420 contour. (Pictures 99 to 103). Utilizing the upper 50 feet for storage purposes a capacity of about 1,600,000 acre-feet would be available to regulate the flow to meet the demand for irrigation. The canal leading from the Williams River reservoir would divert at elevation 1350. With such a reservoir available, the main supply canal could be operated continuously at full capacity. Under this plan, the main supply canal leading to the Williams River reservoir site would have a capacity of 11,000 second-feet. In order to reduce the cross section of the supply canal and the tunnel sections, the conduit was given a grade of one foot to the mile. A site in Virgin Canyon, 17 miles above Boulder Canyon was selected for the diversion dam. (See Plate I, in pocket). The elevation of the Colorado River at this site is 790 feet above sea-level. In order to divert the river at this point, it would be necessary to build a dam to raise the water 790 feet or to elevation 1580 feet above sea level. A careful study was made to determine the probable cost of such a conduit leading to the Williams River reservoir (See pages 60, 61, Appendix A). It was found that the total length of the conduit would be 170 miles, 100 miles of which would be tunnel and 70 miles open canal. In order to carry 11,000 second-feet on a grade of one foot to the mile, it would be necessary to construct a two-barrel concrete lined tunnel, each tunnel being 34 feet in diameter. The open canal, concrete lined, would carry water to a depth of 25 feet, the width of the canal on the bottom being 32 feet with a width at the top of 82 feet. The cost of such a conduit would be about $317,000,000.

It was not possible to prepare a detailed estimate of the cost of the diversion dam on account of insufficient information. It is safe to say that such a dam to raise the water 790 feet could not be built for less than $60,000,000. The water needed for lands on the lower river in the United States and Mexico could be dropped over the diversion dam and utilized for power purposes. A considerable amount of power could therefore be developed at the dam and it seems reasonable to assume that at least half of the cost of the diversion dam could be charged to power development. Under this assumption, the diversion conduit leading to the Williams River reservoir would be charged with $30,000,000 for the diversion dam, making the total cost of the conduit to carry the water to the Williams River, approximately $374,000,000.

Plan D

Plan "D" is the same as Plan "C," with the exception that the water would be carried to the Williams River reservoir site by means of a tunnel 92 miles in length, leading from the Colorado River at a point about 12 miles below Diamond Creek, (See Plate I, in Pocket). A higher dam would be built on the Williams River. In order to obtain a capacity of 11,100 second-feet with a tunnel of one bore, it was necessary to increase the grade to 4 feet to the mile. It was found that a concrete lined tunnel with an inside diameter of 34 feet, constructed to a grade of 4 feet to the mile would have the proper carrying capacity. See Pages 63-65, Appendix A for profile, cross section, and estimate of cost. This tunnel may be built for about $146,000,000. It should be noted that at the point of diversion, the grade elevation of this tunnel would be 1838 feet above sea level. In order to supply the tunnel to full capacity, it would be necessary to raise the water surface of the Colorado River to elevation 1868 feet above sea level. The elevation of the river at the proposed point of diversion is about 1260 feet. It would, therefore, be necessary to construct a diversion dam to raise the water 608 feet. Only general information regarding the conditions at the dam site is available. The formation at the dam site is granite and it seems probable that bed-rock would be found at a reasonable depth below the water surface. The total cost of the diversion dam may not exceed $60,000,000. With the dam completed, water for irrigation of the lands on the lower river in the United States and Mexico could be dropped at the dam, utilizing a head of about 500 feet for power purposes. It seems reasonable to believe that at least half of the cost of the diversion dam would be borne by the power project, leaving $30,000,000 to be charged to the Diamond Creek-Big Sandy Tunnel project. Under this plan the cost of the conduit leading to Williams River reservoir, including contingencies, would be about $215,000,000.

Plan E

A preliminary study was made to determine the feasibility of diverting the Colorado River at a point in the Grand Canyon, the water to be carried by means of a tunnel to the upper basin of the Verde River. Such a tunnel would be more than 90 miles in length and the over-burden would be more than 3,000 feet in depth. While such a tunnel could be built, the time required for its construction would probably exceed 40 years.

Plan F

Assuming that the Glen Canyon dam were built and that the water could be diverted at elevation 3,500 feet above sea level to carry the Colorado River to the upper basin of the Verde, it would require two tunnels, one from the Glen Canyon to the Little Colorado, 50 miles in length, and one from the Little Colorado to the head waters of the Verde River, more than 90 miles in length. On account of the fact that it would be impracticable to work from adits except near the end of the tunnel, the time required for the completion of these tunnels would exceed 40 years.

ARIZONA HIGH LINE CANAL PROJECT
ADOPTED PLAN OF DEVELOPMENT
(Plan D)

The plan of development is shown on Plate I, in Pocket. The distribution system and irrigabale lands are given on Plate II. Plan D, may be better understood if the reader will also study the profile given in Figure 5, keeping in mind that the point of diversion on the Colorado River is 12 miles below Diamond Creek.

The elevation of the saddle in Lone Mountain pass between Bouse Valley and the Gila River basin is 1392 feet above sea level. If the grade of the high line canal at this pass is 1225 feet, it would be necessary to construct a tunnel or cut about 28 miles long.

It was apparent that if the irrigable acreage could be brought nearer the point of diversion, the cost of the canal system would be reduced. To do this and also reduce the size of the cut and the length of Williams River-Bouse tunnel, a plan was adopted which calls for the high line canal to be constructed to Lone Mountain Pass at a higher elevation than 1225. It was decided that a dam could be built in the Box Canyon of the Williams River to raise the water to the 1500 foot contour. By diverting from the Williams River reservoir at elevation 1442 carrying the water through a tunnel 22 miles long, the Bouse Valley could be reached at elevation 1398.

At Lone Mountain Pass the grade elevation of the canal would be 1378.

The outlet of the Diamond Creek-Big Sandy tunnel would have an elevation of 1470 feet. In order to reduce the cross section, the Diamon Creek-Big Sandy tunnel was given a grade of 4 feet to the mile. This tunnel is 92 miles long, the total fall being 368 feet. The grade elevation, therefore, at the head of the tunnel is 1838 feet. Since the elevation of the water surface of the Colorado River at the head of the proposed tunnel is about 1260 feet, it is apparent that a diversion dam must be built to raise the water about 608 feet. If we should increase the height of the dam in the Williams River Canyon, it would be necessary to increase the height of the diversion dam on the Colorado River. By increasing the height of the Williams River dam, the tunnel leading from the Williams River reservoir to Bouse Valley could be given a greater fall and this would reduce its cost. While the cost of this tunnel would be reduced, the cost of the Williams River dam and the diversion dam on the Colorado River would be increased. To strike a balance and determine the most economical plan involving the construction of a distribution system, Lone Mountain cut, the Williams River-Bouse Valley tunnel, the Williams River dam, Diamond Creek-Big Sandy tunnel and the diversion dam on the Colorado, would require considerable work. However, if this should be done, it is believed that the total cost would not be much different from that presented in this report.

The canal system covering 2,000,000 acres of irrigable land below the Williams River, used as a basis for the estimate of cost, is given on Plate I, in Pocket. Some views showing irrigable land are given in Appendix B, see Pictures 107, 107A, 108, 110, 113, and 114.

By means of a two barrel tunnel, 22 miles long, the water could be carried from the Williams River reservoir to a point in the southwestern part of Butler Valley. From the end of this tunnel, the water would be carried in an easterly direction a distance of 40 miles to the summit of Lone Mountain Pass, this point being reached at elevation 1378 feet above sea level. The capacity of the tunnel and main canal to this point would be 17,500 second-feet. At Lone Mountain Pass, the canal would divide in three ways, the Hassayampa branch having a capacity of about 2,000 second-feet would run in an easterly direction covering about 225,000 acres of land in Centennial and Hassayampa valleys and the region north of Buckeye. Running in a southerly direction from Lone Mountain Pass about 15 miles, a canal would lead to Nottbusch Pass. Before reaching Nottbusch Pass, this canal would have a branch running in a westerly direction, carrying about 1,000 second-feet to serve the lands on the south side of Vicksburg Valley. From Nottbusch Pass a canal with a capacity of about 2,500 second-feet would serve some 300,000 acres on the north side of the Gila River. The third branch from Lone Mountain Pass would follow along the north slope of the Eagle Tail and Gila Bend mountains, leading to the Gillespie Dam on the Gila River. This canal at Lone Mountain Pass would have a capacity of about 10,000 second-feet, or sufficient water to serve 125,000 acres between Lone Mountain Pass and the Gillespie Dam and 1,050,000 acres on the south side of the Gila River.

At the Gillespie Dam, (Pictures 109, 109A, 109B) water for the irrigation of 700,000 acres on the south side of the Gila River would be dropped to the Gila River above the dam. The 700,000 acres would be served by extending the present Gillespie Canal, (Gila Water Company) as far west as the Gila Mountains. To reach lands on the south side of the Gila River above the extension of the Gillespie Dam, water would be siphoned, crossing the Gila at the Gillespie dam and delivered on the east side of the river at elevation 975. This canal would lead south, crossing the Southern Pacific Railroad about 6 miles east of Gila Bend, from which point it would run in a southerly direction crossing the Ajo Railroad near Black Gap as shown on Plate II.

Cost Estimates
Arizona High Line
Canal Project

The details regarding unit-costs, design of structures, canal and tunnel sections, amount of material to be excavated, etc., will be found in Appendix A. A cost summary will be given here.

COST SUMMARY
ARIZONA HIGH LINE CANAL PROJECT
(Plan D)

		Cost
Dams		
Colorado River (50% of cost)		$ 30,000,000
Williams River		22,000,000
Tunnels		233,371,000
Siphons		23,806,000
Main Canal		57,152,000
Gillespie Dam (Right of Way)		2,000,000
Lateral System		30,000,000
Miscellaneous Structures		6,538,000
Total		$404,867,000
Contingencies 15%		60,730,000
Additional Contingencies (10% Diamond Creek-Big Sandy Tunnel)		14,600,000
Total Est. Cost		$480,197,000
Credit for Power Assets		
Gila River Site	$24,550,000	
Nottbusch Pass Site	5,800,000	
	$30,350,000	30,350,000
Total Chargeable to 2,000,000 acres		$449,847,000
Estimated cost per acre $225.00.		

CONCLUSIONS AND RECOMMENDATIONS

Foreword:

In addition to the Arizona High Line Project and the Parker-Gila Valley Project, the Commission investigated many smaller projects involving low lands adjacent to the Colorado River. In the conclusions and recommendations, the two major projects will be treated separately, while the smaller projects will be referred to as a group.

Recommendations will also be made regarding river improvements.

MISCELLANEOUS PROJECTS EMBRACING LOW LANDS ADJACENT TO THE COLORADO RIVER

Conclusions:

(a) Unless a feasible, comprehensible, plan of development can be worked out, the area of Arizona land which may be irrigated from the Colorado River will be confined to areas of bottom lands along and adjacent to the Colorado River and a few areas that may be served by pumping from the systems serving these bottom lands or from the Colorado River, aggregating altogether about 300,000 acres.

(b) The data now at hand show that it may be feasible to reclaim 182,000 acres by gravity and 105,000 acres by pumping, or 287,000 acres in all. Of this amount about 45,000 acres are now irrigated (1923).

Recommendations:

Definite data relating to the present Yuma Government Reclamation Project and the Colorado River Indian Reservation Project are available. It is recommended that detailed surveys and cost estimates be made and that reports be prepared to show the most feasible plan for reclaiming the lands in Mohave, Chemehuevis and Cibola Valleys and miscellaneous tracts adjacent to the Colorado River.

PARKER-GILA VALLEY PROJECT

Conclusions:

(a) A dam for power on the Colorado River about five miles above Parker has been investigated and favorably reported upon by Beckman and Linden, Consulting Engineers of San Francisco.

If a diversion and power dam can be constructed at this point to divert water at elevation 440 above sea level, it is possible to irrigate 764,000 acres in Arizona and 310,000 acres in California making over a million acres in all.

(b) On the Arizona side 124,000 acres would be served by gravity, and 640,000 acres by pumping, the maximum lift not exceeding 200 feet.

(c) If the Parker-Gila Valley Project were constructed, power could be developed at the diversion dam, mesa drop south of Parker, at Cibola, and Palo Verde Valleys. The total installed capacity for the four plants would be about 100,000 horse power.

(d) The Parker-Gila Valley Project presents a complicated problem. Involving as it does the development of power, the serving of lands by both gravity and pumping systems, and the serving of lands now irrigated it may be difficult to allocate the cost of the development as between the various areas served.

Only meager data are available on which to base a cost estimate. However, the data presented in this report indicate that about 630,000 acres in Gila Valley, Arizona, may be reclaimed at a cost of $168.00 per acre. More definite data on both the Arizona and California side of the river may show that this cost can be reduced.

(e) The Parker-Gila Valley Project apparently has sufficient merit to justify the expenditure of a considerable sum of money on detailed surveys and the preparation of an engineering report.

(f) The Parker-Gila Valley Project and the lands possible of reclamation in the Palo Verde Valley, Palo Verde Mesa and Chucawalla

Valley, California, may be served from a common diversion dam. Therefore, these projects should be investigated by a Joint Commission.

The members of this Joint Commission should represent the Federal Government and the states of Arizona and California and be charged with the duty of working out a plan of development that will best serve the interests of both States.

Recommendations:

It is recommended,

1. That through appropriate action by the legislatures of Arizona and California, a Joint Commission, as referred to above, be created to investigate the Parker-Gila Valley Project.

2. That sufficient money be appropriated and made available to the Joint Commission to enable it to make all surveys necessary to form the basis for a report which will show definitely the cost of the project and the allocation of the cost as between lands served in California and Arizona.

HIGH LINE CANAL PROJECT

Conclusions:

(a) Investigations made by the Commission indicate that it may be possible to reclaim by irrigation, a net area of about 2,350,000 acres, located in Yuma and Maricopa Counties, Arizona.

(b) In order to reduce the cost per acre, 300,000 acres near the Mexican boundary and 50,000 acres in Quartzsite Valley were excluded from the project.

(c) Soil surveys were not made but the Commission has assumed from its reconnaissance that 2,000,000 acres will produce abundantly when water and humus are added to the virgin soil.

(d) The climatic conditions in Southwestern Arizona favor the growing of crops of one kind or another throughout the year.

(e) In this region intensive farming on small farm units should be practiced.

(f) While the major portion of the crops would be the result of general farming, a part of the land may be found suitable for the growing of fruits and nuts.

(g) Due to the general elevation of the lands to be irrigated and the elevation of certain passes in relation to the source of water supply, it is difficult to devise a feasible plan to bring the water to the irrigable land.

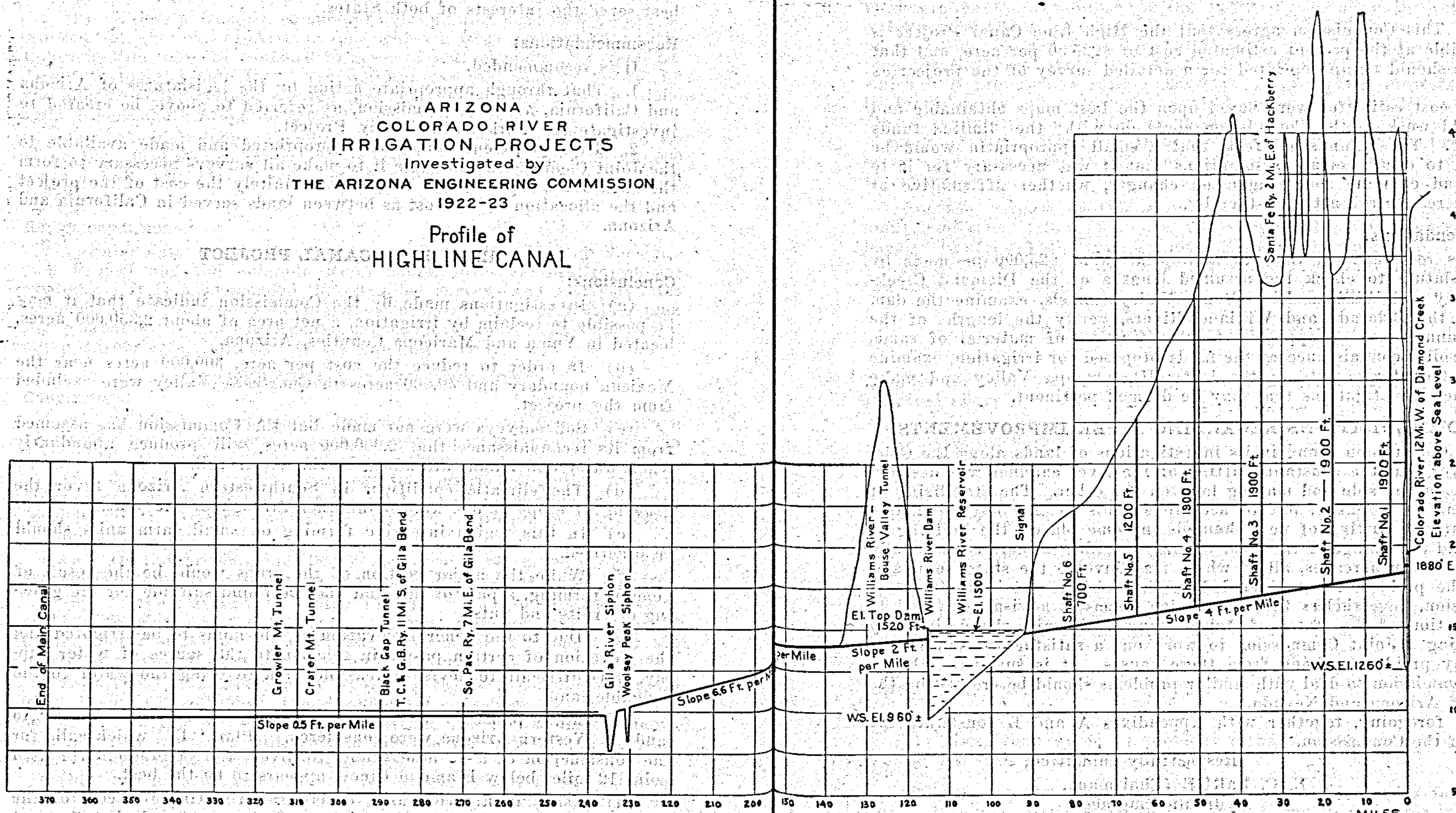
(h) Many plans for diverting the waters of the Colorado River to lands in Western Arizona were considered. Plan "D" which calls for the construction of a 92 mile tunnel to divert the Colorado River at a point 12 miles below Diamond Creek, appears to be the best.

(i) Using Plan "D", as a basis for estimating the cost of the irrigation system to reclaim 2,000,000 acres, it was found that the cost for a concrete lined system down to each 25,000 acre unit, including the distribution system complete would be about $225.00 per acre irrigated.

(j) The Commission believes that the unit costs used in this report are averages attained on work of a similar nature constructed during the last few years. It is possible with high efficiency machines and the large volume of material to be handled to bring the construction costs to a minimum. The quantity of the various classes of material to be moved may vary considerably from that given in this report. A balanced cut and fill section was used as a basis for estimating the

ARIZONA
COLORADO RIVER
IRRIGATION PROJECTS
Investigated by
THE ARIZONA ENGINEERING COMMISSION
1922-23

Profile of
HIGHLINE CANAL



earth and rock quantities in canal excavation. Actual location on the ground will increase the quantities and the lengths of canals as compared with theoretical sections and paper locations.

(k) If the High Line Canal Project be infeasible, more than a million acres of land in Southwestern Arizona must remain a desert forever.

(1) This Commission agrees that the High Line Canal Project is not feasible at the present estimated cost of $225.00 per acre, and that no funds should be appropriated for a detailed survey of the project as a whole.

The cost estimates were based upon the best maps obtainable and such field work as the Commission could do with the limited funds available. The Commission feels that a small appropriatin would be justified to check certain assumptions that it was necessary for it to make, and examine some suggested changes, whether affirmative or negative results are attained thereby.

Recommendations:

It is recommended that an appropriation of $25,000 be made by the legislature to check the assumed lengths of the Diamond Creek-Big Sandy and Williams River-Bouse Valley tunnels, examine the dam sites on the Colorado and Williams Rivers, verify the lengths of the major canals, making approximate classification of material of same, make a soil reconnaissance of the lands proposed for irrigation, examine a suggested storage site in the lower Hassayampa Valley and make such other investigations that may be deemed pertinent.

RECOMMENDATIONS REGARDING RIVER IMPROVEMENTS

The Commission found in its investigations of lands along the Colorado River that the constant shifting of the river channel was destroying land on one side and making land on the other. The stabilizing of the stream is essential, but to accomplish this to the best advantage will mean the cutting of new channels in some places, the building of levees and the change of the river channel in order to more economically irrigate certain acreages, all of which may involve the state boundary. While the problem is not included in the subjects coming under this Commission, nevertheless the Commission deems it advisable to call to the attention of the states of Arizona and California, the desirability of creating a Joint Commission to work out a satisfactory solution of the many problems arising from these causes. It is suggested that a Joint Commission to deal with similar problems should be created by the states of Arizona and Nevada.

The foregoing, together with Appendixes A and B constitute the report of the Commission.

Respectfully submitted,

E. C. LaRUE (Chairman),
Hydraulic Engineer,
U. S. Geological Survey,
Pasadena, California.

PORTER J. PRESTON,
Project Manager,
U. S. Reclamation Service,
Yuma, Arizona.

H. E. TURNER,
Irrigation Engineer with
Arizona State Water Commissioner,
Phoenix, Arizona.

ADEQUACY OF THE WATER SUPPLY

The Arizona Engineering Commission was charged with the duty of determining how much land in Arizona could be irrigated with the waters of the Colorado River. The projects investigated by the Commission embrace areas aggregating more than 2,000,000 acres. The Commission has recommended that a detailed investigation should be made to determine the feasibility of the Parker-Gila Valley Project which embraces 764,000 acres of land in Arizona and 310,000 acres in California. It was also recommended that the sum of $25,000.00 be appropriated for further study of the Arizona High Line Canal Project, under which it is proposed to reclaim 2,000,000 acres. These projects cannot be feasible now nor at any future time unless an adequate water supply is available. The writer, therefore, feels that it is his duty as a member of the Arizona Engineering Commission to call attention to certain facts regarding the flow of the lower Colorado River and its use for irrigation.

For the purpose of this statement, the writer will accept the analysis of stream flow data given in Appendix B, of the report "Problems of Imperial Valley and Vicinity," Senate Document No. 142, 67th Congress, 2nd Session. The table given below appears on page 37 of the above named report.

Table No. 9—Averages 1903-1920

		Acre-feet
Average discharge of Colorado River at Yuma, 1903-1920		17,400,000
Diverted above by Yuma project		150,000
Total discharge		17,550,000
Discharge of Gila		1,080,000
Estimated at Boulder Canyon		16,470,000
Past depletion (1)		560,000
Remainder at Boulder Canyon		15,910,000
Future depletion		
Development, upper basin	4,230,000	
Reservoirs in canyon section	2,070,000	
		6,300,000
Remaining water		9,610,000

(1) Less than given in previous estimates, because embracing a shorter period of time.

The above table shows that with all demands for water for irrigation in the upper basin satisfied and with reservoirs built for irrigation and power development, there would remain at Boulder Canyon an average annual flow of 9,610,000 acre feet.

In Senate Document No. 142, referred to above, the following assumptions were made.

"Annual gross demand for irrigation, gravity 4.40 acre-feet per acre; pump, 3.50 acre-feet per acre. Annual net demand above Laguna Dam, consumptive use 3.00 acre-feet per acre."

A Synopsis of Table No. 12
(Senate Doc. No. 142)

	Above Laguna Dam	Below Laguna Dam Gravity	Below Laguna Dam Pumping	Grand Total
Acres	305,000	1,532,000	183,000	2,020,000
Demand (ac-ft. per acre) (Net)	3.00	4.40	3.50	4.10
Total demand acre-feet	915,000	6,740,000	641,000	8,300,000

The data given above show the future annual supply at Boulder Canyon to be 9,610,000 acre-feet and the annual demand for 2,020,000 to be 8,300,000 acre-feet. These data indicate a surplus in supply of 1,310,000 acre-feet annually.

The results of the investigations just completed by the Arizona Engineering Commission, show the need for further study to determine definitely how much land in Arizona and California can be irrigated with the waters of the Colorado River. The total area of the projects studied by the Commission, including low lands adjacent to the river, was about 2,600,000 acres in Arizona. If these projects should be proven feasible at this or any future time, the flow of the Colorado below the Grand Canyon must be sufficient to serve an area of more than 4,000,000 acres. Assuming a duty of 4.00 acre-feet per acre the annual requirement would be more than 16,000,000 acre-feet. The average supply being 9,610,000 acre-feet, it must be apparent that the annual water supply would be deficient by about 6,000,000 acre-feet. The writer, therefore, wishes to call attention to the need for a broad investigation, for it is his opinion that the water supply of the Colorado River may not be sufficient to reclaim the lands which may be found commercially feasible of development.

If the 2,000,000 acres in the lower Gila Valley were irrigated the return flow would pass down the Gila River and reach the Colorado River below Laguna Dam but above the present heading of the Imperial Canal. This return flow would probably amount to more than 1,500,000 acre-feet annually. This water would be available for the irrigation of lands in Mexico. The water from the Colorado River would be carried to the Gila basin in concrete lined tunnels and canals, the loss of water would be almost negligible. The greater part of water now lost in the river channel below Grand Canyon would be saved and the return flow would be available for use in Mexico. Such a plan of development would result in putting the water to its highest use.

The need for additional areas of irrigated land is not especially urgent. It is, therefore, suggested that sufficient time be taken to make surveys and prepare a report showing a comprehensive plan for the development of the Colorado River as a whole.

Each year lands on the Arizona side of the river are menaced by the flood waters. The excellent land in Cibola Valley, Arizona, is being rapidly destroyed by the river. The Yuma Valley must fight the floods each year in order to save its levees and irrigated lands. The Palo Verde Valley lands are also endangered by the summer flood water. The flood menace in the Imperial Valley in California and Mexico is even more serious.

The floods should be placed under control as quickly as possible. The writer wishes to suggest that a detailed study should be made of the Mohave Valley reservoir site for in his opinion this site, if developed, will solve the flood problem.

The dam site is located in Mohave Canyon about two and one-half miles below Topock. The side walls are composed of granite and the width between the walls at the water surface is 240 feet. A dam to raise the water 125 feet would create a reservoir with a capacity of 8,-200,000 acre-feet a capacity sufficient to cut the most serious floods at Yuma to less than 30,000 second-feet, excepting floods from Gila River.

The writer was loaned to the State of Arizona by the U. S. Geological Survey, Department of the Interior, to assist that state in solving its problems involving the use of the waters of the Colorado River. He, therefore, feels that it is his duty to state frankly his opinions resulting from the investigations made by the Arizona Engineering Commission.

1. The further investigations recommended by the Arizona Engineering Commission may show that it is feasible to reclaim by irrigation, large areas in Arizona if a proper plan for diverting the waters of the Colorado River is worked out.

2. While the larger irrigation projects on the lower river in Arizona and California may not be feasible at this time, these projects may be feasible 20 or 30 years from now.

3. Taking the Colorado River basin as a whole, many projects are listed which are not feasible of development today, yet it has been suggested that the right to divert water for the development of these projects shall never be denied.

4. The larger projects on the lower river are no more visionary than certain projects in other parts of the basin. It is, therefore, suggested that a way be found to reserve the right to develop these larger irrigation projects in Arizona and California, should they be found feasible of development at some future time.

E. C. LaRUE.

APPENDIX A

Duty of Water

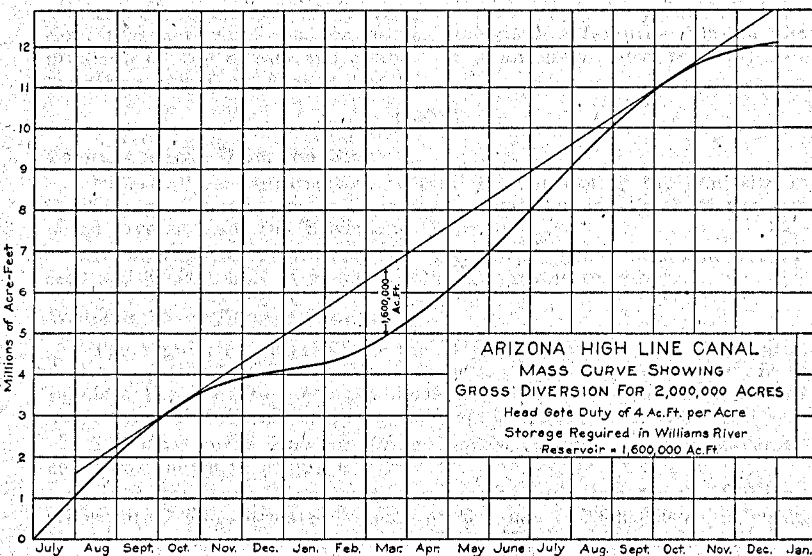
It has been assumed that 3 acre-feet of water per acre should be delivered to the land, to which one acre-foot per acre is added to cover waste, seepage, and evaporation losses in the conduits, making the gross duty 4 acre-feet per acre. The gross diversion at the headgate to irrigate 2,000,000 acres under the Arizona High Line Canal Project, would be 8,000.000 acre-feet, and 764,000 acres under the Parker-Gila Valley Project, provided it is considered as an independent project from the High Line Canal, would require 3,056,000 acre-feet.

From records of the Salt River Project on the east and the Yuma Project on the west, an average has been computed to establish the monthly use of water for the projects under consideration. Table No. 1 shows the distribution by months of the water required.

MONTHLY USE AND WATER REQUIRED

TABLE NO. 1

Month	Monthly Use: Salt River Project %	Monthly Use: Yuma Project %	Monthly Use: Arizona High Line Parker-Gila %	Amount Required: Arizona High Line Project Sec. Ft.	Amount Required: Parker-Gila Valley Project Sec. Ft.
Jan.	2.0	2.7	2.4	3,130	1,040
Feb.	3.0	5.1	4.0	5,760	1,910
March	7.0	9.4	8.2	10,700	3,540
April	10.0	9.4	9.7	13,100	4,320
May	13.0	9.9	11.4	14,800	4,930
June	14.0	12.0	13.0	17,500	5,700
July	13.0	12.8	12.9	16,800	5,560
Aug.	11.0	13.3	12.2	15,900	5,270
Sept.	10.0	11.8	10.9	14,700	4,880
Oct.	9.0	7.2	8.1	10,500	3,500
Nov.	6.0	3.5	4.7	6,320	2,100
Dec.	2.0	2.9	2.5	3,250	1,070
TOTALS	100.0	100.0	100.0	11,040 (Mean)	3,660 (Mean)



ARIZONA HIGH LINE CANAL
MASS CURVE SHOWING
GROSS DIVERSION FOR 2,000,000 ACRES
Head Gate Duty of 4 Ac.Ft. per Acre
Storage Required in Williams River
Reservoir = 1,600,000 Ac.Ft.
1,600,000 Ac.Ft.
Millions of Acre-Feet
0
1
2
3
4
5
6
7
8
9
10
11
12
July Aug Sept. Oct. Nov. Dec. Jan. Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov. Dec. Jan.

Figure 6

STRUCTURES

In planning the works the governing features of the High Line Project are:

1. Elevation of the irrigable lands.
2. Elevation of the Lone Mt. and Nottbusch passes.
3. Elevation of the Williams River Reservoir.
4. Depth of overburden—Diamond Creek-Big Sandy Tunnel.
5. Elevation of the Colorado River, below Diamond Creek

The controlling features of the Parker-Gila Valley Project are:

1. Elevation of irrigable lands.
2. Elevation of Siphons across Gila River.
3. Elevation of Parker Diversion Dam on Colorado River.
4. Pumping lift at Lighthouse Rock.

The great distance of the irrigable lands from the points of diversion, together with the controlling topographic features, limited the gradient of the canals and tunnels to a minimum with resulting low velocities and large cross sections.

DAMS

Colorado River Diversion Dam

Practically no information is available concerning the dam site in the canyon of the Colorado River just below Diamond Creek at the proposed diversion for the High Line Canal.

It was assumed, however, that the cost of the dam would not exceed $60,000,000, half of which may be chargeable to power.

Williams River Storage Dam

The regulating reservoir on the Williams River is a very essential feature of the High Line Canal Project. By using this reservoir to regulate the flow to meet the demand for irrigation, a uniform flow may be maintained in the Diamond Creek-Big Sandy tunnel.

The mass curve showing storage required in the Williams River reservoir is shown in Figure 6.

An estimate has been made of a gravity type dam for the Williams River site. The estimated volume of the dam is 2,080,000 cubic yards. For topography and cross section of the Williams River dam site see Figure 7.

The walls of the canyon at the dam site consist of a gneiss and rhyolite formation. The depth to bed-rock has been estimated not to exceed 40 feet below the water surface.

A spillway capacity of 60,000 second-feet should be provided.

Parker Diversion Dam—Colorado River

The Parker dam site, which is located on the Colorado River about 5 miles above Parker has been investigated by the Beckman-Linden Engineering Corporation, Consulting Engineers of San Francisco.

The estimated cost of this dam is based on the report of the above named engineering firm.

TUNNELS

100 Miles of Tunnel, Plan C

One of the most difficult engineering features of the High Line Canal Project is the conveyance of water from the point of diversion on the Colorado River to the Williams River Reservoir.

Two methods of conveying the water from the Colorado River to the Williams River Reservoir were considered.

The first plan considered was a canal and tunnel line, the point of diversion being located in Virgin Canyon, 17 miles above Boulder Canyon dam site (Plan C). The elevation of the water surface at the proposed point of diversion is 790 feet above sea level. In order to obtain a grade of one foot per mile in the conduit, leading to Williams River, it would be necessary to raise the water surface of the Colorado River to elevation 1580 feet.

Such a conduit would have a length of 170 miles, 70 miles of which would be open canal and the remaining 100 miles would be in tunnel.

In order to carry 11,000 second-feet on a grade of one foot to the mile, it would be necessary to construct a two-barrel concrete lined tunnel, each tunnel being 34 feet in diameter.

The open canal, concrete lined, would carry water to a depth of 25 feet, the width of the canal on the bottom being 32 feet, with a width at the water surface of 82 feet. The cost of such a conduit would be about $317,000,000.

See Table No. 2 and Figure 8.

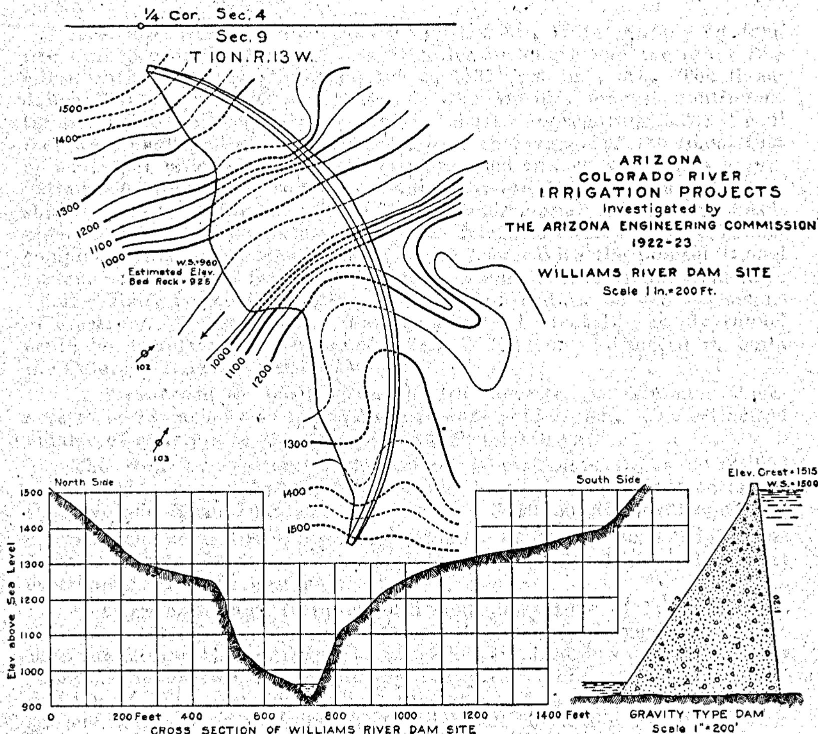
ARIZONA HIGH LINE CANAL PROJECT
TABLE NO. 2
ESTIMATED COST—MAIN SUPPLY CANAL—PLAN C
VIRGIN CANYON TO WILLIAMS RIVER RESERVOIR

Structure	Length Miles	Excavation Cu. Yards	Concrete Lining Cu. Yds.	Cost
TUNNELS, dia. 34'				
Twin bores	100	42,000,000	6,920,000	$300,200,000
CANAL				
Earth excavation	52.5	15,225,000	766,500	9,949,000
CANAL				
Rock Excavation	17.5	4,375,000	252,000	6,895,000
TOTALS	170	61,600,000	7,938,500	$317,044,000

Diamond Creek-Big Sandy Tunnel

It will be noted that Plan C involves the construction of a conduit with tunnels aggregating 100 miles in length and 70 miles of open canal. The cost of such a conduit would be prohibitive. A shorter route for the conduit leading to Williams River Reservoir was found by assuming the diversion at a point on the Colorado River, 12 miles below Diamond Creek. The water can be conveyed to the Williams River Reservoir by a tunnel 92 miles in length. An intensive study was made as to the practicability of constructing a tunnel of the unprecedented length of 92 miles.

The Diamond Creek-Big Sandy Tunnel is located below elevation 2,000 feet.



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ARIZONA
COLORADO RIVER
IRRIGATION PROJECTS
Investigated by
THE ARIZONA ENGINEERING COMMISSION
1922-23
WILLIAMS RIVER DAM SITE
Scale 1 In. = 200 Ft.
W.S. = 960
Estimated Elev. Bed Rock = 925
North Side
South Side
Elev. above Sea Level
CROSS SECTION OF WILLIAMS RIVER DAM SITE
Elev. Crest = 1515
W.S. = 1500
GRAVITY TYPE DAM
Scale 1" = 200'

Figure 7

By reference to Bulletin 435 of the U. S. Geological Survey by N. H. Darton, it will be observed that below elevation 2000 feet, the formation is granite, which is favorable for the construction of deep tunnels.

Another important factor is the time required to construct such a long tunnel. The alignment was planned so that the maximum number of headings could be used with shafts of a minimum depth. It was found that six shafts could be located with a total depth of 9500 feet, with a maximum depth of shaft of 1900 feet, which would divide the tunnel into lengths varying from 4 miles to 16 miles. With a grade of 4 feet per mile, it would require one concrete lined bore 34 feet in diameter of standard horseshoe type to carry 11,000 second-feet of water.

It is interesting to note that in the Catskill Water Supply System, two tunnels were constructed, one 18 miles in length and the other 18.1 miles, with shafts ranging from 108 to 1187 feet in depth. The Shendaken Tunnel, recently completed, is the world's longest continuous tunnel, being 18.1 miles long. Seven shafts aggregating 3,238 lineal feet were employed during construction or an average of 180 lineal feet of shaft per mile of tunnel. In our proposed tunnel, six shafts aggregating 9500 lineal feet would be required or less than 104 lineal feet of shaft per mile of tunnel. These shafts would permit of 14 main headings to be worked simultaneously. The Niagara Falls Pressure Tunnel completed this year has a diameter of 32 feet. With the pioneer tunnel system such as used on the 5-mile Rogers Pass tunnel on the Canadian Pacific Railway, other headings could be opened as needed by means of crosscuts. It is estimated that the Diamond Creek-Big Sandy tunnel could be completed in ten years, which is the time estimated to build the Colorado River diversion dam.

It is proposed to line the tunnel with concrete, the minimum thickness to be 12 inches and the average thickness 18 inches. The estimated volume of concrete in the lining is 3,183,000 cubic yards.

The rock excavation in the tunnel is estimated to be 20,424,000 cubic yards. A part of this material may be used in the construction of the Colorado River Diversion Dam and the William River storage dam.

The Diamond Creek-Big Sandy tunnel of the Arizona High Line Canal Project was designed as a single bore, this being the most economical from the cost point of view.

It is realized that, in practice, a continuous flow of 11,000 second-feet of water might not be maintained throughout the year in a single bore tunnel and that it might be necessary to close down the tunnel for repairs, one or two months during the year. This would cause a reduction of the water delivered to the land. If the construction of this project were to be undertaken, it might be advisable to design twin bores of smaller diameter instead of a single bore as estimated.

A profile and section of the Diamond Creek-Big Sandy Tunnel is shown in Figure 9.

Table No. 7 shows the properties of tunnels on the Parker-Gila Valley Project and Table No. 16 gives the same data for tunnels on the High Line Canal Project.

CANAL CONSTRUCTION

Attention should be directed to the fact that in keeping with the whole report, very conservative methods were used to estimate the canal costs. The average transverse slope was assumed to be 2% and an economic cut was used throughout. This is an ideal condition that would never be attained even in flat, level, country.

It should also be pointed out that the lengths of canals as determined by paper location would be increased if location surveys were made.

Taking these various factors into consideration, estimates based on location surveys would increase the cost of the canals.

Surface Drainage

Much of the desert country traversed by the canals considered in this report is subject to heavy torrential storms, which occur with irregular frequency. While the aggregate run-off from this source is small, it should be remembered that the rate of runoff is very high.

This condition has resulted in a multiude of sand washes, ranging from 5 to 200 feet in width and draining in a direction at right angles to the canal. Each one of these washes is a menace to the safe operation of a canal. Such menace varying with the size of the wash and the rate of run-off.

It is believed that the proper method of taking care of this cross-drainage is by the use of inverted siphons, culverts and flumes. At many locations above the canals, a number of smaller washes can be diverted into one large wash, under which the canal would be carried through a spihon. One reason for adopting this plan would be the additional protection it offers to farms below the canal, making possible the reclamation of considerable acreage now cut up into small tracts by these washes. At favorable locations, use can be made of culverts under the canals or flumes over them.

It is thought that a fair estimate of the structures necessary to take care of this cross surface drainage would be to assume that, on the average, it would be necessary to construct a siphon 150 feet long every two miles, and one minor structure, such as a culvert or flume, every two miles. The estimated cost includes the excavation of material necessary to divert all the surface drainage to these cross drainage structures.

Culverts are to be avoided as much as possible, as they are essentially pressure conduits and tend to fill up with debris as the flow of storm water subsides, or they may become clogged during the storm causing the water to overflow into the canal with attendant damage.

Steel Siphons

The cost estimates are based on designs which call for reinforced concrete siphons for heads less than 80 feet and steel siphons for heads greater than 80 feet. To facilitate maintenance, these steel siphons are designed to be supported above ground on concrete piers. The only exception being the Gila River siphon on the Parker-Gila Valley project. On this siphon where the pipes cross the channel it is proposed to bury them under the river-bed after protecting the steel with an external coat of reinforced concrete having a minimum thickness of 6 inches.

Tables Nos. 8 and 17 give the principal features and costs of steel siphons on the Parker-Gila Valley and the High Line Canal projects, respectively.

Concrete Lining

Concrete lining has been estimated for all canals having a capacity of 200-second-feet or more. The use of concrete lining has the following advantages:

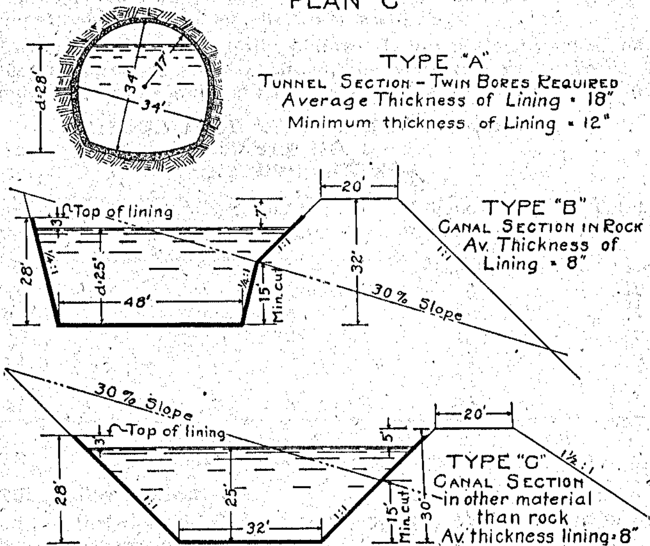
1. Offers less resistance to flow than an earth canal, hence the section may be made smaller.
2. Lessens the danger from breaks, and permits carrying the water

ARIZONA HIGH LINE CANAL

SUPPLY CONDUIT

FROM COLORADO RIVER TO WILLIAMS RIVER RESERVOIR

PLAN C



PROPERTIES

	TYPE		
	A (each bore)	B	C
Bottom Width in ft.	—	48	32
Depth in ft.	28	25	25
Hyd. Rad. in ft.	10.4	13.5	13.9
Area of Water sq. ft.	852	1394	1425
Wetted Perimeter	82	103	103
Value of "n"	.014	.014	.014
Slope	.0002	.0002	.0002
Fall in ft. per mile	1.06	1.06	1.06
Velocity-ft. per sec.	6.80	7.93	8.07
Quanity in sec. ft.	5,800	11,000	11,600
Exc.-cu. yds. per mile	210,000	250,000	290,000
Con. Lining cu. yds. per mile	34,600	14,400	14,600

Figure 8

further above the ground surface, thus lessening the amount of excavation required.

3. Lessens loss by seepage. In systems of the magnitude described in this report, the loss in an unlined canal would undoubtedly exceed 50% of the amount diverted. This would necessitate headworks and supply conduits of at least 50% greater capacity, and the question of water supply would become serious. The seepage water from earth canals would water-log large areas of adjacent farm land.

4. Breaks are less liable to occur than in an earth canal system and the damage from any break that may occur would be less, due to the smaller amount of pondage between wasteways.

5. Lessens growth of aquatic plants. In an unlined system based on the controlling features as outlined, the velocities would be so low that vegetable growths would thrive, making maintenance expensive.

ARIZONA HIGH LINE CANAL PROJECT
TABLE NO. 3
CONCRETE LININGS

Depth of Water	Average Thickness	Freeboard on Lining	Total Freeboard
Feet	Inches	Inches	Feet
5 to 9	3	6	2
10 to 14	4	6	2
15 to 19	5	12	3
20 to 24	6	12	4
25 to 29	7	18	5
30 to 35	8	18	6

POWER PLANTS

Parker-Gila Valley Project

There are three power sites on this project. At the diversion dam, about five miles north of Parker, there will be a drop of 90 feet for the water passing the dam. It is assumed that the Colorado River will be regulated by a dam somewhere above the Parker diversion dam, which will reduce the mean maximum flow in the river below the Parker diversion dam to 10,000 second-feet. With this amount passing through the power plant, 82,000 horse power can be developed. Lesser amounts of power can be developed at the Reservation and Cibola sites, where water is released from the main canal to supply the low lying areas along the river.

At all three power plants, the period when the maximum amount of water is available for power is coincident with the peak demand for power at the two pumping plants, and since enough power cannot be developed in this project to meet this demand, the installed capacity in all three power plants has been assumed large enough to handle the maximum flow. See Table No. 5.

High Line Canal Project

Two drops occur on the canal system where power can be developed. One is at the Gila River crossing, and the other is on the Palomas Lateral, where it enters Nottbusch Valley.

In estimating the value of these plants as revenue producers, the installed capacities have been assumed which correspond to the flow of water available for 50% of the time. By taking a liberal view of the possibilities of the project, it has been assumed that the total output of these plants can be sold at a price of one half cent per K. W. H. at the point of production. Table No. 24 gives a summary of the principal features of these two plants.

PUMPING PLANTS

Pumping is confined to the Parker-Gila Valley Project, for which two plants are provided. The Parker Mesa plant, which is to lift 60 second-feet under a head of 165 feet, requires 1460 horse power. This plant, however, is small in comparison with the Lighthouse Rock pumping plant, where the lift is 200 feet and the capacity is 5400 second-feet. At this plant the power required at the pumps is 160,000 horse power. Each of the ten units assumed for this installation would consist of a 16,000 horse power motor direct-connected to a centrifugal pump having a capacity of 540 cubic feet per second. See Table No. 6.

TRANSMISSION LINE

A transmission line 87 miles long will be required on the Parker-Gila Valley Project to transmit power from the Parker power plant, at the diversion dam, to the Lighthouse Rock pumping plant. The power which must be purchased to make up the difference between the amount required by the pumping plants and the amount that can be generated, can also be carried over this line.

PURCHASE OF POWER

The amount of energy which must be purchased totals 458,600,000 K. W. H. per annum. The peak demand would come in the summer, and the minimum demand would occur during the months of December and January.

It has been assumed that this power can be purchased at a price of ¾ of a cent per K. W. H. at the pumping plant.

UNIT COSTS

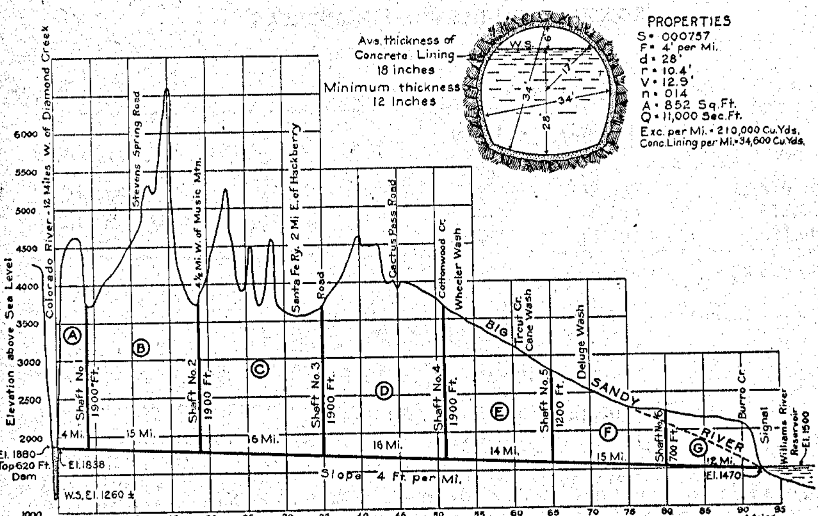
In determining the unit costs for these projects, data were obtained from construction contractors and engineers as well as from recent cost records of actual work performed by the government and by pivate organizations, dealing with large works.

In works of the magnitude of these projects, it is reasonable to assume that records for construction would be lowered as to speed and cost, due to improved methods and specially designed machinery. Materials could be purchased at the lowest market prices on account of the enormous quantities involved.

Table No. 4 gives the principal unit costs used.

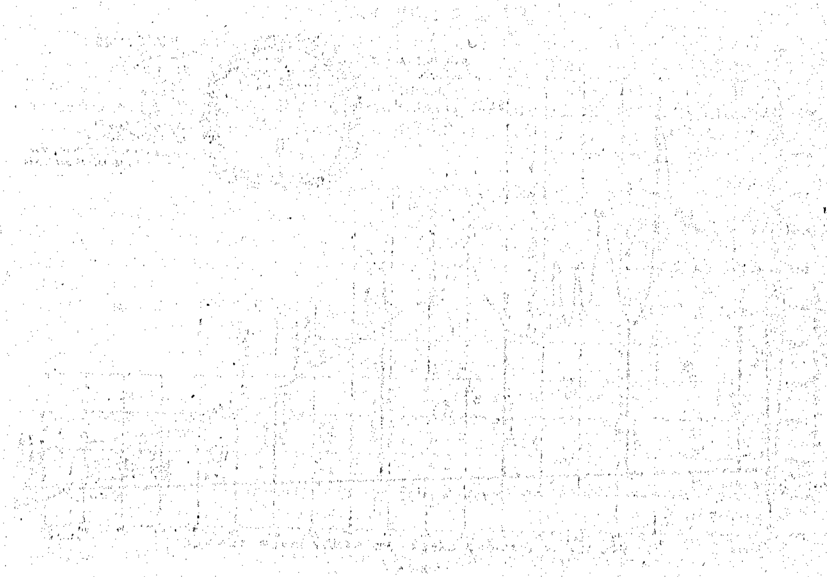
TABLE NO. 4
UNIT COSTS

Kind of Work	Unit	Unit Cost
Tunnel Excavation	Cu. Yd.	$5.00-$5.50
Tunnel Shafts	Lin. Ft.	120.00
Concrete Lining	Cu. Yd.	10.00
Reinforced Concrete in Pipes	" "	23.00
Reinforced Concrete Transitions	" "	16.00
Reinforced Concrete Siphon Piers	" "	14.00
Plain Concrete	" "	10.00
Canal Excavation, Rock	" "	1.00
Canal Excavation, Earth	" "	0.15



PROFILE OF DIAMOND CREEK - BIG SANDY RIVER TUNNEL

Figure 9



PARKER-GILA VALLEY PROJECT

TABLE NO. 5

POWER PLANTS

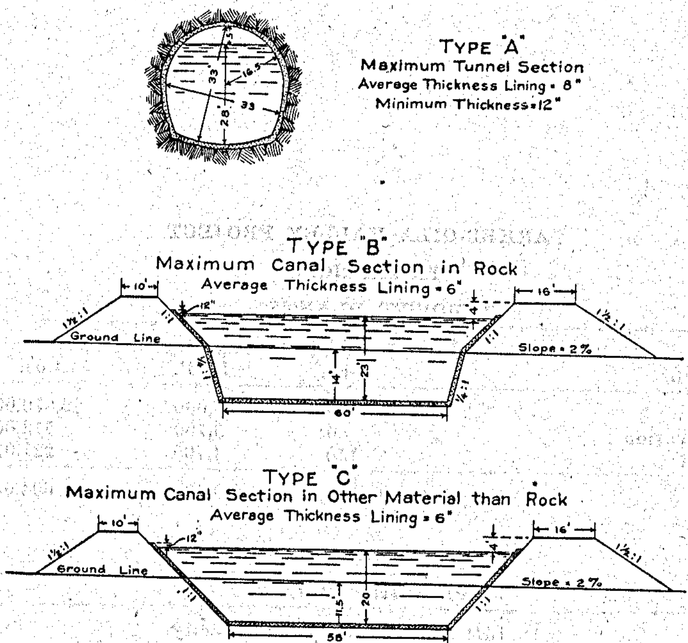
Name	Head Ft.	Capacity H. P.	Cost
Parker	90	82,000	$2,870,000
Reservation	80	5,700	513,000
Cibola	150	1,700	221,000
		89,400	$3,604,000

TABLE NO. 6

PUMPING PLANTS

Name	Lift Ft.	Capacity Sec. Ft.	Capacity H. P.	Cost
Parker Mesa	165	60	1,460	$ 135,000
Lighthouse Rock	200	5400	160,000	4,580,000
			161,460	$4,715,000

PARKER-GILA VALLEY PROJECT

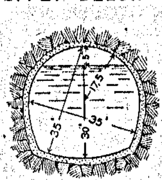


PROPERTIES

	TYPE		
	A	B	C
Bottom width in feet	—	60	58
Depth in feet	28	23	20
Hyd. Rad. in feet	10.1	13.8	13.6
Water Section in sq.ft.	822	1573	1560
Wetted Perimeter in feet	81.4	114	115
Value of "n"	.014	.014	.014
Slope	.00019	.00005	.00005
Fall in feet per mile	1	.264	.264
Velocity in feet per second	6.55	4.36	4.32
Discharge in sec.feet	5380	6860	6740
Excavation in cu.yds. per mile	198,000	182,550	165,000
Concrete Lining, in cu.yds. per mile	34,500	11,360	11,340

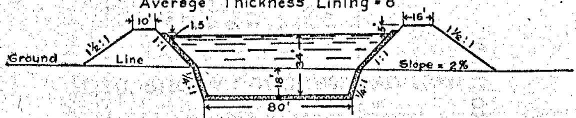
Figure 10

ARIZONA HIGH LINE CANAL PROJECT
MAIN SUPPLY BELOW WILLIAMS RIVER RESERVOIR

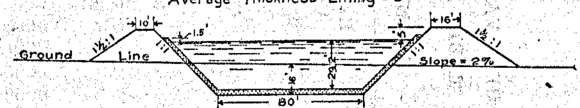


TYPE "A"
Twin Bores Required
Average Thickness Lining = 18"
Min. Thickness = 12"
Maximum Tunnel Section

TYPE "B"
Maximum Canal Section in Rock
Average Thickness Lining = 8"



TYPE "C"
Maximum Canal Section in Other Material than Rock
Average Thickness Lining = 8"



PROPERTIES

	TYPE		
	A (Each Bore)	B	C
Bottom width in feet	—	80	80
Depth in feet	30	34	29.2
Hyd. Rad. in feet	10.7	19.7	19.6
Water Section in sq. ft.	932	3200	3189
Wetted Perimeter in feet	87	162	163
Value of "n"	.014	.014	.014
Slope	.00038	.00005	.00005
Fall in feet per mile	2	.264	.264
Velocity in feet per second	9.40	5.46	5.43
Discharge in sec. feet	8760	17500	17300
Excavation in cu. yds. per mile	224,000	315,000	316,000
Concrete Lining in cu. yds. per mile	35,500	21,700	21,800

Figure 11

PARKER-GILA VALLEY PROJECT

TABLE NO. 7

TUNNELS

Name	Length Miles	Dia. Ft.	No. Bores	Excavation Cu. Yds.	Concrete Lining Cu. Yds.	Capacity Sec. Ft.	Total Cost
Parker	1	36	1	240,000	41,500	6680	$ 1,615,000
Lighthouse Rock	16	33	1	3,170,000	552,000	5370	21,370,000
Muggins	6	29	1	900,000	165,000	3660	6,150,000
Wellton No. 1	1	26	1	121,000	23,200	2800	837,000
Wellton No. 2	1	25	1	113,000	22,000	2600	785,000
Mohawk	4	21	1	328,000	70,000	1500	2,340,000
Gila Mt.	1	10	1	27,000	7,000	800	205,000
TOTAL COST TUNNELS							$33,302,000

PARKER-GILA VALLEY PROJECT
TABLE NO. 8
STEEL SIPHONS

Name	Length Miles	Dia. Pipes Ft.	No. Pipes	Capacity Sec. Ft.	Cost
Osborne Wash	0.2	19	2	6600	$ 253,000
Gila River	5.0	13	4	3600	8,739,000
TOTAL COST					$8,992,000

TABLE NO. 9
MISC. SHORT CONCRETE SIPHONS

Canal Capacity Sec. Ft.	No. Siphons	Cost Each	Total Cost
6000 to 7000	13	$102,000	$1,325,000
5000 to 6000	32	94,000	3,010,000
3000 to 4000	0		
2000 to 3000	42	63,000	2,645,000
1000 to 2000	21	48,000	1,010,000
Less than 1000	85	20,000	1,700,000
			$9,690,000

PARKER-GILA VALLEY PROJECT
TABLE NO. 10
WASTEWAYS

Name	Capacity Sec. Ft	Cost
Castle Dome Landing	5400	$ 83,000
Norton	1000	35,000
Wellton	2800	60,000
Mohawk	1500	44,000
Miscellaneous		100,000
TOTAL COST		$322,000

TABLE NO. 11

RAILROAD CROSSINGS

Name	Capacity Sec. Ft.	Cost
Santa Fe	6500	$ 45,000
S. P.	200	8,000
		$ 53,000

PARKER-GILA VALLEY PROJECT

TABLE NO. 12

DIVISION WORKS

Name	Capacity Sec. Ft.	Cost
Muggins	4900	$ 95,000
Gila Mountain	3600	81,000
		$176,000

TABLE NO. 13

MISC. CROSS DRAINAGE FLUMES

Canal Capacity Sec. Ft.	No. Siphons	Cost Each	Total Cost
6000 to 7000	14	$14,000	$ 196,000
5000 to 6000	31	13,000	403,000
3000 to 4000	1	10,000	10,000
2000 to 3000	42	8,700	365,000
1000 to 2000	21	7,000	147,000
Less than 1000	85	3,800	323,000
			$1,444,000

PARKER-GILA VALLEY PROJECT
TABLE NO. 14
MAIN CANAL SYSTEM

		Unit	Main Canal	North Gila Branch	South Gila Branch	Yuma Mesa Branch	Totals
Rock Sec.	Length	Miles	4	11	9	3	27
	Excavation	Cu. Yd.	617,740	423,460	1,116,360	91,660	2,249,220
	" Cost		$ 617,740	$ 423,460	$1,116,360	$ 91,660	$ 2,249,220
Earth Sec.	Length	Miles	105	62	160	36	363
	Excavation	Cu. Yd.	15,451,670	2,427,670	8,398,470	807,200	27,085,010
	" Cost		$ 2,317,750	$ 364,150	$1,259,770	$ 121,080	$ 4,062,750
Concrete Lining	Quantity	Cu. Yd.	1,027,766	209,988	640,026	62,565	1,940,345
	Cost		$10,277,660	$2,099,880	$6,400,260	$ 625,650	$19,403,450
	Total Costs		$13,213,150	$2,887,490	$8,776,390	$ 838,390	$25,715,420

PARKER-GILA VALLEY PROJECT

TABLE NO. 15

SUMMARY OF COSTS

PARKER DAM (Inc. Headworks)	$ 4,700,000	$ 4,700,000
POWER PLANTS		
Colorado River	2,870,000	
Reservation	513,000	
Cibola	221,000	3,604,000
TRANSMISSION LINE, 87 Mi. @ $20,000	1,740,000	1,740,000
PUMPING PLANTS		
Parker Mesa	135,000	
Lighthouse Rock	4,580,000	4,715,000
TUNNELS		
Lighthouse Rock	21,370,000	
Muggins	6,150,000	
Miscellaneous	5,782,000	33,302,000
SIPHONS		
Osborne	253,000	
Gila River	8,739,000	
Misc. (Short Siphons)	9,690,000	18,682,000
MISCELLANEOUS STRUCTURES		
Wasteways	322,000	
R. R. Crossings	53,000	
Division Works	176,000	
Cross Drainage Flumes	1,444,000	1,995,000
MAIN CANAL SYSTEM		
Excavation	6,312,000	
Lining	19,403,000	25,715,000
LATERAL SYSTEM 764,000 acres @ $15	11,460,000	11,460,000
CONTINGENCIES 15%	15,887,000	15,887,000
TOTAL CONSTRUCTION COST		$121,800,000
Less proportion of Dam chargeable to California	2,000,000	
Less charge of $100 per acre against 124,000 acres in Parker and Cibola Valleys	12,400,000	14,400,000
COST OF 640,000 ACRES AT $168.00		$107,400,000

COST OF OPERATION—POWER AND PUMPING PLANTS

Salaries	$ 46,000	
Maintenance and Depreciation	235,000	
Purchase of Power	3,440,000	
TOTAL	$3,721,000	per annum

Cost of pumping per acre served $5.82 per annum.

ARIZONA HIGH LINE CANAL PROJECT

TABLE NO. 16

TUNNELS

Name	Length Miles	Dia. Ft.	No. Bores	Cu. Yds. Excavation	Cu. Yds. Conc. Lining	Capacity	Total Cost
Diamond Creek-Big Sandy	92.0	34	1	20,424,000	3,183,000	11,000	$146,502,000
Williams River-Bouse Valley	22.0	35	2	9,856,000	1,562,000	17,500	70,568,000
Harquahala	1.0	35	2	448,000	71,000	16,200	2,950,000
Maricopa	2.0	30	1	324,000	58,600	3,000	2,206,000
Black Gap	2.6	26	1	312,000	60,600	2,000	2,166,000
Crater	3.0	17	1	171,000	40,200	700	1,257,000
Growler	2.5	12	1	85,000	21,250	300	637,000
Eagle Tail	1.0	33	1	198,000	34,500	3,700	1,335,000
White Tank	6.0	26	1	720,000	140,400	2,000	5,004,000
Bighorn	2.0	16	1	100,000	24,600	1,500	746,000
TOTAL	134.1						$233,371,000

ARIZONA HIGH LINE CANAL PROJECT
TABLE NO. 17
STEEL SIPHONS

Name	Length Miles	Dia. Pipes Ft.	No. Pipes	Capacity Sec. Ft.	Total Cost
Woolsey Peak	1.3	18	3	8,900	$2,414,000
Gila River	3.0	14	2	3,200	1,220.000
Hassayampa	0.5	14	1	650	102,000
TOTAL					$3,736,000

ARIZONA HIGH LINE CANAL PROJECT
TABLE NO. 18
MISC. SHORT CONCRETE SIPHONS

Canal Capacity Sec. Ft.	No. Siphons	Cost Each	Total Cost
Above 16,000	19	$160,000	$3,040,000
8,000 to 10,000	16	120,000	1,920,000
4,000 to 6,000	42	89,600	3,760,000
3,000 to 4,000	44	75,000	3,300,000
2,000 to 3,000	31	63,000	1,950,000
1,000 to 2,000	69	49,000	3,380,000
Below 1,000	272	10,000	2,720,000
TOTAL			$20,070,000

ARIZONA HIGH LINE CANAL PROJECT
TABLE NO. 19
WASTEWAYS

Name	Capacity Sec. Ft.	Cost
Cunningham Wash	17,500	$ 295,000
Centennial Wash	9,500	220,000
Woolsey Peak	9,000	215,000
S. P. Crossing	3,000	125,000
Deadman Gap	2,500	112,000
Gila Bend	5,000	160,000
Sentinel	4,000	142,000
Eagle Tank	3,000	125,000
Mohawk	2,000	100,000
Nottbusch	2,500	112,000
Lone Mt.	2,000	100,000
Hassayampa	1,500	88,000
Miscellaneous		250,000
		$2,044,000

ARIZONA HIGH LINE CANAL PROJECT

TABLE NO. 20

RAILROAD CROSSINGS

Name	Capacity Sec. Ft.	Cost
Santa Fe	17,000	$ 80,000
S. P.	3,000	25,000
S. P.	5,200	42,000
S. P.	5,000	40,000
S. P.	4,800	38,000
S. P.	4,500	36,000
S. P.	4,500	36,000
T. C. & G. B.	2,500	21,000
TOTAL		$318,000

TABLE NO. 21

DIVISION WORKS

Name	Capacity Sec. Ft.	Cost	Remarks
Lone Mt.	16,500	$400,000	3 way structure
Nottbusch	5,000	100,000	
Woolsey Peak	8,900	200,000	
TOTAL		$700,000	

ARIZONA HIGH LINE CANAL PROJECT

TABLE NO. 22

CROSS DRAINAGE FLUMES

Capacity Canal	Number Structures	Cost Per Structure	Total Cost
Sec. Ft.			
Above 16,000	20	$22,000	$ 440,000
8,000 to 10,000	15	16,000	240,000
4,000 to 6,000	42	12,000	504,000
3,000 to 4,000	44	10,000	440,000
2,000 to 3,000	31	9,000	279,000
1,000 to 2,000	69	7,000	483,000
Below 1,000	272	4,000	1,090,000
TOTAL			$3,476,000

ARIZONA HIGH LINE CANAL PROJECT

TABLE NO. 23

MAIN CANAL SYSTEM

		Unit	Main Canal	Palomas Branch	Hassayampa Branch	Gillespie Canal	Totals
Rock Sec.	Length Excavation " Cost	Miles Cu. Yd.	58 6,266,300 $ 6,266,300	9 723,100 $ 723,100	14 401,530 $ 401,530	24 2,699,020 $ 2,699,020	105 10,089,950 $10,089,950
Earth Sec.	Length Excavation " Cost	Miles Cu. Yd.	308 22,681,330 $ 3,402,200	144 5,437,870 $ 815,680	120 3,344,130 $ 501,620	310 15,286,000 $ 2,292,900	882 46,749,330 $ 7,012,400
Concrete Lining	Quantity Cost	Cu. Yd.	1,912,942 $19,129,420	423,399 $4,233,990	242,373 $2,423,730	1,426,296 $14,262,960	4,005,010 $40,050,100
	Total Costs		$28,797,920	$5,772,770	$3,326,880	$19,254,880	$57,152,450

ARIZONA HIGH LINE CANAL PROJECT

TABLE NO. 24

POWER PLANTS

Name of Plant	Gila River	Nottbusch
Head in Feet	252	150
Flow available 50% of time	4,320 S. F.	1,860 S. F.
Installed Capacity	92,800 H. P.	23,800 H. P.
Cost per Installed H. P.	$ 43.00	$ 58.00
TOTAL COST	$ 3,990,000	$ 1,380,000
Max. Output per Annum K. W. H.	458,000,000	118,000,000
Revenue @ $0.005 per K. W. H.	$ 2,290,000	$ 590,000
Operation and Maintenance @ $0.001 per K. W. H.	$ 458,000	$ 118,000
Interest and Depreciation @ 9%	$ 359,000	$ 124,000
Net Profits	$ 1,473,000	$ 348,000
Value of Plant—Net Profits Capitalized @ 6%	$24,550,000	$ 5,800,000

ARIZONA HIGH LINE CANAL PROJECT
TABLE NO. 25
RECAPITULATION OF COSTS

Canal or Structure	Length Miles	Capacity From Sec. Ft.	Capacity To Sec. Ft.	Cost	Total Cost
MAIN SUPPLY CONDUIT					
Colorado River Dam (50% cost)				$ 30,000,000	
Diamond Creek Big Sandy River Tunnel	92.0	11,000	11,000	146,502,000	$176,502,000
MAIN HIGH LINE CANAL					
Williams River Dam				$ 22,000,000	
Williams River-Bouse Tunnel	22.0	17,500	17,500	70,568,000	
Harquahala Tunnel	1.0	16,200	16,200	2,950,000	
Woolsey Peak Siphon	1.3	8,900	8,900	2,414,000	
Gila River Siphon	3.0	3,200	3,200	1,220,000	
Miscellaneous Tunnels	10.1	3,000	300	6,266,000	
Miscellaneous Short Siphons	5.2	17,500	190	10,035,000	
Miscellaneous Wasteways		17,500	1,000	1,102,000	
Miscellaneous R. R. Crossings		17,000	2,500	126,000	
Miscellaneous Division Works				259,500	
Miscellaneous Cross Drainage Flumes				1,738,000	
Canal Construction	366.0	17,500	190	28,797,900	
Lateral System				12,375,000	$159,851,400
PALOMAS BRANCH					
Miscellaneous Tunnels	7.0	3,700	2,000	$ 6,339,000	
Miscellaneous Short Siphons	2.2	2,500	190	2,408,000	
Miscellaneous Wasteways				127,000	
Miscellaneous Division Works				108,500	
Miscellaneous Cross Drainage Flumes				417,000	
Canal Construction	153.0	2,500	190	5,772,780	
Lateral System				4,500,000	$ 19,672,280

HASSAYAMPA BRANCH					
Miscellaneous Tunnels	2.0	1,500	1,500	$ 746,000	
Hassayampa River Siphon	0.5	650	650	102,000	
Miscellaneous Short Siphons	1.9	2,000	190	2,007,000	
Miscellaneous Wasteways		2,000	1,000	214,000	
Miscellaneous Division Works				95,200	
Miscellaneous Cross Drainage Flumes				348,000	
Canal Construction	134.0	2,000	190	3,326,850	
Lateral System				3,375,000	$ 10,214,050
GILLESPIE BRANCH					
Miscellaneous Short Siphons	4.7	5,700	190	$ 5,620,000	
Gila River Dam				2,000,000	
Miscellaneous Wasteways		5,000	1,000	601,000	
Miscellaneous R. R. Crossings		5,200	4,500	192,000	
Miscellaneous Division Works				236,800	
Miscellaneous Cross Drainage Flumes.				973,000	
Canal Construction	344.0	5,700	190	19,254,920	
Lateral System				9,750,000	$ 38,627,720
Grand Total					$404,867,450

ARIZONA HIGH LINE CANAL PROJECT

TABLE NO. 26

SUMMARY OF COSTS

	Cost	Total Cost
DAMS		
Colorado River (50% cost)	$ 30,000,000	
Williams River	22,000,000	
		$ 52,000,000
TUNNELS		
Diamond Creek-Big Sandy	$146,502,000	
Williams River-Bouse Valley	70,568,000	
Harquahala	2,950,000	
Miscellaneous	13,351,000	
		$233,371,000
SIPHONS		
Woolsey Peak	$ 2,414,000	
Gila River	1,220,000	
Hassayampa	102,000	
Misc. (Short Siphons)	20,070,000	
		$ 23,806,000
MISCELLANEOUS STRUCTURES		
Wasteways	$ 2,044,000	
R. R. Crossings	318,000	
Division Works	700,000	
Cross Drainage Flumes	3,476,000	
		$ 6,538,000
MAIN CANAL SYSTEM		
Excavation and Concrete Lining	$ 57,152,000	
Gillespie Dam (Right of Way)	2,000,000	
		$ 59,152,000
LATERAL SYSTEM		
2,000,000 acres @ $15.00		30,000,000
TOTAL COST		$404,867,000
Contingencies 15%		60,730,000
Additional Contingencies		
(Diamond Creek-Big Sandy Tunnel 10%)		14,600,000
		$480,197,000
(Cross Cost per acre $233.00)		
CREDIT FOR POWER ASSETS		
Gila River site	$ 24,550,000	
Nottbusch site	5,800,000	
		$ 30,350,000
Net cost per acre $225.00		$449,847,000